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Spectrophotometry of Gaseous Nebulae in the Magellanic Clouds. L. H. ALLER, senior postdoctoral fellow at the *Australian National University*, on leave from the University of Michigan; AND D. J. CAULKNER, *Mount Stromlo Observatory, Australian National Observatory*.—With a photoelectric spectrum scanner attached to the 50- and 74-inch reflectors at Mt. Stromlo and the 26-inch reflector at the Mt. Bingar Field Station we have obtained spectral scans of ten objects in the Small Magellanic Cloud (SMC) and 33 objects in the Large Magellanic Cloud (LMC) selected from Henize's list of emission nebulosities. These diffuse nebulae show a wide range in excitation. A substantial difference in excitation may exist between two nebulous patches lying side by side. Object No. 144 in Henize's catalogue appears to have the highest excitation of any object in the LMC, being comparable with a typical planetary rather than a diffuse nebula. Special attention has been paid to 30 Doradus in the LMC and to NGC 346 in the SMC. Although the $HeI\ \lambda 4471\text{ \AA}$ to $H\gamma\ \lambda 4340\text{ \AA}$ intensity ratio may be slightly smaller in NGC 346 than in 30 Doradus, the He/H ratios in the two clouds are probably comparable.

The general appearance of the spectra of diffuse nebulae in the galaxy, the LMC, the SMC, and in M33 seems to be about the same, suggesting that nebular excitation patterns and probably chemical compositions also are similar in these members of the local group of galaxies.

A Program of Stellar Photometry at 3 to 4 Microns. PHILIP E. BARNHART, WALTER E. MITCHELL, JR., AND RONALD E. ROLL, *Perkins Observatory, Delaware, Ohio*; AND WILLIAM H. HAYTIE, *Eastman Kodak Company, Rochester, New York*.—Observations of stellar radiation in the spectral region 3.2 to 4.2 μ are being made using the Perkins Observatory 69-inch reflector equipped with

an infrared photometer designed and constructed by the Apparatus and Optical Division of the Eastman Kodak Company.

The present pilot-model photometer is equipped with detector and interference filter combinations to allow observation of the spectral regions 2.0 to 2.4 μ (n -type lead sulfide) and 3.2 to 4.2 μ (p -type lead sulfide). The latter region is centered in the 3 to 4 μ atmospheric window. Calibrations are made by direct comparison with a blackbody source.

Preliminary results in the 2.0 to 2.4 μ region compare favorably with previously published observations and with blackbody calculations. There seems to be a tendency for later-type stars to show a higher PbS index than indicated by blackbody calculations for their temperatures.

Infrared magnitudes are given for 15 stars from deflections obtained in the 3 to 4 μ region using nitrogen-cooled plumbide cells.

A second photometer is being designed to include in addition to detectors for the two spectral regions mentioned a helium-cooled, copper-doped germanium detector for the purpose of measuring stellar radiation in the 8 to 14 μ atmospheric window.

Measurement of Microwave Radiation at 3.45 cm from the Planetary Nebula NGC 6543. A. H. BARRETT, W. E. HOWARD III, AND F. T. HADDOCK, *The Observatory*, M. E. BAIR, J. J. COOK, AND L. G. CROSS, *Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan*.—Microwave radiation from the planetary nebula NGC 6543 has been detected using the University of Michigan 85-foot radio telescope and a ruby maser operating at 8700 Mc (3.45 cm wavelength). Observations taken on the nights of March 28–29, 1960, and May 18–19, 1960, give an antenna temperature of $0.034 \pm 0.013\text{ }^\circ\text{K}$ corresponding to a flux density of $4.0 \times 10^{-27}\text{ w m}^{-2}\text{ (c/s)}^{-1}$ with an internal con-

sistency of $\pm 40\%$. Confirming observations were taken on the nights of March 10–11, 1960 and August 16–17, 1960. The above flux is a factor of 0.8 of that obtained by C. R. Lynds at Green Bank at a wavelength of 21 cm (C. R. Lynds, private communication) and a factor of 0.31 of that obtained by T. A. Matthews at Cal Tech at a wavelength of 31 cm (J. G. Bolton, 12th General Assembly of URSI, London, 1960). These values suggest a non-thermal radio component from the planetary nebula. However, the possible uncertainties in the absolute values makes this inference highly uncertain. More accurate absolute measurements are needed in this wavelength range.

A North-South Asymmetry in Location of Solar Sources of Great Geomagnetic Storms.

BARBARA BELL, *Harvard College Observatory*.—At the 106th meeting of the Society, the author presented evidence that, in the years 1937–1959, a major flare in the northern solar hemisphere had about four times greater probability than a similar southern flare of being followed within three days by a great magnetic storm. This concentration of great-storm sources in the solar north occurred about equally in each of the three sunspot cycles, No. 17, 18, and 19.

Evidence for a preferred hemisphere for great-storm sources in earlier cycles has now been examined. Most of the data for this study were taken from the Royal Greenwich Observatory's "Sunspot and Geomagnetic-Storm Data, 1874–1954." The Greenwich data reveal that over 50% of the total observed spotted area, and over 50% of the great spots ($A \geq 500$), occurred in the solar north in cycles 14–18, and in the south in cycles 12 and 13. Earlier data, in part from published records of Spoerer, in part generously made available by A. S. Milsom from his work with unpublished drawings of Schwabe, indicate that the solar north was the more spotted in cycles 8 and 9, and south in cycles 10 and 11.

Regarding geomagnetic activity, a substantial majority of the great storms apparently came from northern active centers in cycles 16–19, and from southern centers in cycles 10, 13 and 14; the two hemispheres contributed about equally in cycle 15; cycles 11 and 12 are probably, but less clearly, south-dominant. In most of the earlier cycles, as in 17–19, the degree of asymmetry in location of storm sources is increased when the lower limit for what shall be called a "great storm" is raised. Usually, the hemisphere that is more spotted in a given cycle produced more of the great storms; but not always, for the two curves are not perfectly in phase. The asymmetry in location of great-storm sources does not appear proportional to, and far exceeds in magnitude, the asymmetry in spottedness.

This work was supported by the Air Force Cambridge Research Center, through a contract with Harvard University.

Changes in the Periods of RR Lyrae Stars in Omega Centauri.

EMILIA PISANI BELSERENE, *Ruthenferd Observatory, Columbia University, New York, New York*.—This is the continuation of a study, begun by W. C. Martin (*Ann. Sterrewacht Leiden* 17, part 2, 1938), of period changes in the globular cluster Omega Centauri. There are, on this program, 32 of his 68 stars, all RR Lyrae variables of subclasses *a* and *b*, with regularly repeating light curves. For these 32 stars, as well as for the others, Martin had found increasing periods to predominate. The average rate of change was $+5 \times 10^{-10}$ days per day, or about 0.2 days per million years. The new observations, in 1947–8 and in 1956–8, provide two new epochs for the determination of periods. For the 32 stars the mean period was

0.6608544 from 1896 to 1933,
0.6608580 from 1931 to 1935,
0.6608584 from 1933 to 1947,
0.6608600 from 1947 to 1957.

Thus the new observations confirm the trend detected by Martin. The average rate of change of period, over the whole time interval, is $+4 \times 10^{-10}$ days per day. Individual values range from -31×10^{-10} to $+52 \times 10^{-10}$; the question arises as to the possibility that the trend is only apparent, resulting from the chance distribution of the extreme values. This does not appear to be the case, however. The rates of change show a frequency distribution with a reasonably narrow maximum at $+3 \times 10^{-10}$. It is not very likely that this distribution arose through chance selection of a sample from a population whose average period is constant. Unless some unsuspected systematic error is at work, then the periods of these regular RR Lyrae stars tend to increase with time.

The Light Variation and Orbital Elements of

AK Herculis. L. BINNENDIJK, *Flower and Cook Observatory, University of Pennsylvania*.—Photoelectric observations are presented of 520 yellow and 518 blue magnitudes of AK Herculis made during one night in 1959 and ten nights in 1960. The observations of four successive nights of exceptionally good quality in June 1960 showed definitely that there was an interval of constant light during the minima of 35-minutes' duration.

The orbital solution shows that primary minimum is caused by annular eclipse and secondary minimum by total eclipse. The curvature of the eclipse curve around the time of primary minimum is slight which indicates a small coefficient of limb darkening for

the greater star. Theoretical light curves were computed for different coefficients of limb darkening and ratios of radii. It was found that $x=0.4$ and $k=0.45$ achieves the best agreement with the observations. The semimajor axis of the greater star is found to be $a_0=0.54$ and the inclination 78° .

Theoretical Evaluation of Atmospheric Drag Effects in the Motion of an Artificial Satellite, Part II. DIRK BROUWER AND GEN-ICHIRO HORI, *Yale University Observatory, New Haven, Connecticut*.—In a previous paper, presented at the Pittsburg meeting, it was shown that the solution of the motion of an artificial satellite with atmospheric drag under the gravitational field of the oblate earth is reduced to that of the equations

$$\frac{dL''_k}{dt} = -C_D A V_{pk}'' \exp(-\alpha r),$$

$$\frac{dl''_k}{dt} = \frac{\partial F^{**}}{\partial L''_k} + C_D A V_{qk}'' \exp(-\alpha r).$$

The quantities $V_{pk}'' \exp(-\alpha r)$, $V_{qk}'' \exp(-\alpha r)$ are evaluated from the drag-free theory (Brouwer, *Astron. J.* **64**, 378, 1959). The third and the fourth harmonics are included as well as the second. The method of canonical transformation is extensively applied in this evaluation. Short-period terms of the drag-free problem produce secular and long-period terms. This is one important result of the coupling effect between drag and oblateness.

The solution contains secular, mixed secular, long-period, and short-period terms. As for the variables L_j'' and l_j'' ($j \neq 1$), the solution is obtained up to the orders $C_D k_2$, k_2^2 for secular and mixed secular terms; up to the order C_D for periodic terms. For the variables l_1'' , long-period terms are complete to the order C_D/k_2 . The solution is complete to the order e^4 for the variables L_j , l_2'' and $l_1''+l_2''$. The physical nature of the solution is discussed.

405-Mc Observations of the Galactic Center. B. F. BURKE AND J. W. FIROR, *Carnegie Institution of Washington, Department of Terrestrial Magnetism*.—It is known from 3.8-cm observations that the radio continuum brightness distribution in the vicinity of the galactic center is complex. The most intense radiation at that wavelength comes from a source of small angular diameter, perhaps 3 or 4 minutes of arc, superimposed on a broader, somewhat less intense emission region about 30 minutes of arc in diameter. These will be referred to as sources A and B, respectively. Along the galactic plane, and symmetrically disposed about $\frac{1}{2}$ deg to either side of these central sources, are two discrete

sources (C and D) of approximately equal brightness. The entire system of sources is superimposed on a fainter background, detectable over a region several degrees in diameter. We have made observations of this region at 405 Mc, with a fan-beam antenna having an east-west resolution of 12 minutes of arc. From these observations several deductions can be made.

1. The two sources C and D, which lie close to the hydrogen ring described by Rougoor and Oort, could not be seen, and must be thermal in nature.

2. The right ascension of the peak of the central complex at 405 Mc, $17^h 42^m 41^s$ (1950.0), agrees with the 3.8-cm position of source B within 1 minute of arc. The observed intensity requires that at least part of the central region A and B emit nonthermally. The observations are consistent with the interferometer measurements of the Meudon group at 1420 Mc, who found that source A apparently is thermal, while source B is nonthermal.

3. At 405 Mc, the separation of the central complex A and B from the disk component of the galactic background cannot be made unambiguously, implying that most of the nonthermal radiation from the central regions may well originate, not in a discrete central source, but in a central concentration of the galactic nonthermal background.

Three Southern Spectroscopic Binaries. WILLIAM BUSCOMBE AND PAMELA M. MORRIS, *Mount Stromlo Observatory, Canberra, Australia*.—Radial velocities have been measured from three-prism spectrograms (36 Å/mm at $H\gamma$) exposed at the Casse-

TABLE I.

HD	114911	184035	217792
Name	η Mus	BS 7422	π PsA
Vis. mag.	4.8	5.9	5.1
Spectrum	B8 V	A3 III	F0 IV
Prev. obs.	6	0	15
New obs.	11	12	26
P, days	20.0052	4.625	356.567
γ , km/sec	-8.1	+11.9	-7.3
K, km/sec	56.5	72.5	21.5
e	0.12	0.09	0.70
ω	120°	315°	10°
T-JD 2400000	20606.722	36702.433	34968.266
$10^{-8} a \sin i$, km	15.4	4.6	75.3
$f(m)$, solar masses	0.36	0.18	0.13

grain focus of the 30-inch reflector, during the years 1955-60. Combined with similar data for η Mus and π PsA obtained 40 years ago by the Lick Observatory in Santiago, and also measures for π PsA from the Cape, these make possible the determination of orbits. The duplicity of HD 184035 was first discovered here in 1959. Irwin's tables were used in deriving the preliminary orbits. Details of observations and orbital parameters are given in Table I.

Anomalous Abundances of Atmospheric Xenon Isotopes. A. G. W. CAMERON, *Atomic Energy of Canada Limited, Chalk River, Ontario*.—Mass spectrometric analyses of xenon in cosmogenic gases extracted from various stone meteorites (principally by J. H. Reynolds) show the same relative isotopic abundances except for variations in Xe^{129} . These variations may be attributed to the decay of I^{129} with a half-life of 17 million years, and indicate that an interval of approximately 120 million years passed between the cessation of nucleogenesis in the material which formed the solar system and the freezing of xenon in the meteorite parent bodies. The relative abundances of *all* the isotopes in atmospheric xenon differ from those of meteoritic xenon. The largest differences occur for the isotopes Xe^{129} , Xe^{131} , Xe^{132} , Xe^{134} , and Xe^{136} , which are unshielded against formation by the decay of fission products. Kuroda has suggested that the atmospheric excess of these isotopes is due to spontaneous fission of Pu^{244} (80-million-year half-life) incorporated in the primitive earth. The present calculations support this view. The anomalous abundances of the shielded isotopes Xe^{124} , Xe^{126} , Xe^{128} and Xe^{130} appear to have been produced by a neutron-capture process. It is extremely unlikely that a sufficient number of neutrons can have been produced in the atmosphere to account for the anomalies. The order of magnitude of the anomalies can be accounted for if it is assumed that about 10% of the atmospheric xenon has come from the sun, where it has been subjected to the neutron flux associated with deuterium thermonuclear reactions. While one can expect that the earth's magnetic field will deflect away the gases of the solar wind, the high mass-to-charge ratio of the xenon ions may allow them to be captured into the atmosphere.

This work was done at Mount Wilson and Palomar Observatories and supported by the Air Force Office of Scientific Research.

Narrow-Band Photometry of Babcock's Magnetic Star HD 215441. ROBERT C. CAMERON, *NASA Theoretical Division, Silver Spring, Maryland*, AND CHARLES PERRY, *Berkeley Astronomical Department, University of California*.—The eighth-magnitude A0p star HD 215441 was discovered by Horace W. Babcock in 1959 to have by far the largest effective magnetic field known. In October, 1959 the intensity was 34.40 ± 266 gauss. The star is unique in that its Zeeman pattern has been clearly resolved.

We observed Babcock's star photoelectrically on 14 of 17 consecutive nights in September, 1960 with the 20-inch reflector of the Palomar Observatory in narrow bands at 5500, 4700, 4100 (half-width 200 Å), and 3500 Å (half-width about 300 Å), during the course of a program of photoelectric narrow-band photometry of B. Strömgren. The respective ranges

of variation in the four wavelengths were approximately 0.18, 0.23, 0.23, and 0.27 mag. Pending final reduction, we tentatively note an increase in the range of variation from a value of 0.14 magnitudes, derived through broad-band photoelectric photometry (effective wavelength 4200 Å) during the period August, 1959–February, 1960 by T. Jarzebski, Wroclaw Observatory. The six light-curves in *yellow, blue, violet, ultraviolet, v-b*, and *u-v* are approximately 180° out of phase with *b-y*. The ranges of *b-y*, *v-b*, and *u-v* are approximately 0.07, 0.07, and 0.10 mag., respectively.

Jarzebski derived a period of 9.49 days. Combination of his epoch with ours yields a possible period of 9.475 days. A slight suggestion of short-period variation seems to be worth following up.

The star is unusually bright in the ultraviolet for its spectral class.

The remainder of this paper is based upon unpublished observational data of Strömgren. The anomalous location of several magnetic stars in his (*l,c*) classification, based on the strengths of *H-beta* and the Balmer discontinuity, respectively, is described in connection with the possibility of using narrow-band criteria for the discovery of magnetic stars.

Neutrino Emission Processes in Old Stars. HONG-YEE CHIU, *The Institute for Advanced Study, Princeton, New Jersey*.—When created inside stars, neutrinos will escape, thus carrying energy away. This is due to the long mean free path l of neutrinos at normal densities ($l \gg 10^{13}$ cm, the maximum dimension of normal stars). Important neutrino emission processes are: (1) The URCA process (Gamow, G., and Shönberg, J., *Phys. Rev.* **59**, 539, 1941; Cameron, to be published; Chiu, to be published): $(Z, A) \rightarrow (Z+1, A) + e^- + \bar{\nu}$, and $(Z+1, A) + e^- \rightarrow (Z, A) + \nu$. (2) The neutrino bremsstrahlung process: $e^- + (Z, A) \rightarrow e^- + (Z, A) + \nu + \bar{\nu}$ [Pontecorvo, B. M., *JETP* **36**, 1615, 1959 (Translation: *Soviet Phys. JETP* **9**, 1148, 1959); Gandel'man, G. M., and Pinaev, V. S., *JETP* **37**, 1072, 1959 (Translation: *Soviet Phys. JETP* **37**, 764, 1959)]. (3) The photo-neutrino process: $e^- + \gamma \rightarrow e^- + \nu + \bar{\nu}$ (Chiu and Stabler, to be published). (4) The pair annihilation process: $e^- + e^+ \rightarrow \nu + \bar{\nu}$. (5) The blackbody radiation process: $\gamma + \gamma \rightarrow \nu + \bar{\nu}$ (Chiu and Stabler, to be published). Processes (4) and (5) are related, since at $T > 5 \times 10^8$ °K electron pairs will be created in thermal equilibrium with radiation. Anomalous rates of energy dissipation have been found for processes (4) and (5). A typical example: the relaxation for cooling for pure radiation at $T = 10^9$ °K is one year. The effect of neutrino emission on stellar evolution is to shorten the time of evolution in which the central temperature exceeds 5×10^8 °K. It can be proved

in general that neutrino emission cannot act as a thermostat in stars with $M > 1.4 M_{\odot}$ in which the hydrostatic equation still holds.

The Use of a Digital Computer in the Solution for the Elements of Eclipsing Binary Stars.

GEORGE W. COLLINS AND C. M. HÜFFER, *Washburn Observatory, University of Wisconsin*.—It is the purpose of this paper to describe a recent application of a high-speed digital computer to the solution for the elements of eclipsing binary stars.

The method of reduction is primarily that of Kopal using rectified light curves. A description of the method and how it was adapted to machine use form the main body of the paper. The machine formulation has been carried out in a sufficiently general language so as to make it useable on several different high-speed computers. Details of the machine requirements are also given.

The star selected for discussion is S Cancri, using photoelectric observations made at the McDonald Observatory, and in Madison in 1951, and at Kitt Peak in 1960. The eclipse is total. The fundamental equation includes a term for the computation of the darkening coefficient. It is hoped to use this method for other stars including AR Cas and VV Ori.

The Determination of the Velocity Vector of a Space Vehicle from Apparent Changes in the Angular Separations of Stars.

OLIVER C. COLLINS AND WALTER F. HILTNER, *Boeing Airplane Company—Aero Space Division, Seattle 24, Washington*.

—In the course of interplanetary travel the apparent relative positions of stars and the angular measurements of their separations will not be altered significantly by the changes of location which are achieved by the vehicle. Nevertheless, on account of the aberration of light, while the vehicle is in motion small but highly significant variations of these angular positions of the stars will be apparent. These facts provide a basis for the immediate determination of the speed of the vehicle and of its instantaneous direction of motion. Also, a continuous record of the velocity vector against time would provide the basis for a determination of the dead-reckoning position in space. This paper provides a mathematical development appropriate for interplanetary vehicular speeds of the same order as the orbital speed of the earth.

On the Adams Prize Problem for 1856.

ALLAN F. COOK AND FRED A. FRANKLIN, *Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge, Massachusetts*.—The question of the dynamical stability of Saturn's rings has a direct and immediate bearing upon all discussions of struc-

ture and particle size. The famous essay of J. C. Maxwell considers in elegant detail the dynamical stability of a ring of zero thickness in which collisions are not important. His calculation for the case of finite thickness of the ring is in error and we have modified it to arrive at a criterion of dynamical stability increasing Maxwell's upper limit on the density by more than an order of magnitude.

Consideration of the effect of collisions leads to the following results: First, the accommodation coefficient for interparticle collisions must exceed some minimum value (about one-half), or input to random motions from friction would exceed output to radiation of heat generated in the particle surfaces by impacts, and the ring would expand in thickness. Second, the efficiency of the above input diminishes as the ring becomes thinner so that an equilibrium between the two processes may be expected at much greater random velocities and thickness of the ring than from thermal motions alone. The collapse to a thickness corresponding to thermal motions will only occur if the accommodation coefficient is approximately unity. Third, the combination of an accommodation coefficient in the above range and of viscosity operates to stabilize the rings against infinitesimal disturbances provided the density does not exceed approximately one-fifth that of Saturn.

This work was supported in part by the Air Force Cambridge Research Center through a contract with Harvard University.

Motions in Bright Rim Structures in Diffuse

Nebulae. G. COURTES AND S. R. POTTASCH, *Observatory of Marseille and Observatory of Paris, Meudon (Seine et Oise), France*.—Present theory (Kahn, F., *Bull. Astron. Inst. Neth.* 12, 187, 1954; Pottasch, S. R., *ibid.* 14, 29, 1958) regards the bright rim structures in diffuse nebulae as ionization fronts, the result of interaction of ionizing radiation from an exciting star with dense un-ionized matter in the nebulae. This theory can be definitely confirmed by observing the predicted motion of the ionized material away from the ionization front at about the speed of sound. Proper motion studies will not reveal this motion because there is no way of marking a particular point in the ionized gas, so that recourse must be made to radial velocity measurements. Because these bright rim structures are observed primarily in the plane of the sky any radial velocity shift will be observed at the same position as the dark matter.

The observations were taken at the Newtonian focus of the 193-cm telescope of the Observatory of Haute Provence, with a Fabry-Perot interferometer, especially built for this purpose (Courtes, G., *Ann. astrophys.* 23, 115, 1960). It enables one to obtain

a field of view $6'$ on a side and is equipped with a filter which limits the spectral range to $H\alpha$ and the $[NII]$ lines. Motions greater than 1.5 km/sec can be detected. Pictures of bright rim structures in NGC 6611, IC 1396, and NGC 7000 have been obtained.

On Second Helium Ionization as a Cause of Cepheid Instability. JOHN P. COX, *Cornell University, Ithaca, New York*.—Exact numerical solutions of the complete eighth-order system of linearized nonadiabatic pulsation equations have been obtained for simplified Cepheid envelope models in radiative equilibrium with a polytropic structure, using the IBM 704 computer at the Smithsonian Astrophysical Observatory, Cambridge, Massachusetts. The principal purpose of the investigation was to test the hypothesis that second helium ionization, occurring at a critical depth in a stellar envelope, is the ultimate source of Cepheid instability. In the pulsation equations, radiative transfer was assumed and second helium ionization was taken explicitly into account. Reasonable values were assigned to the real and imaginary parts of the complex pulsation frequency because interiors were not available to fix these values. It was found, however, that the solutions in the outer regions (the regions of greatest interest for the Cepheid problem) were not very sensitive to the precise values of these constants. The negative dissipation in the envelopes was calculated and the positive dissipation in the interiors was estimated in an approximate way. For population I Cepheid envelope models with reasonable helium abundances and radii near the empirical values, the negative dissipation in the envelopes approximately balances the positive dissipation in the interiors, thus rendering the actual sign of the total dissipation uncertain. Second helium ionization in the envelopes is therefore at least a significant factor in determining the over-all pulsational stability of the star and may conceivably be capable of producing incipient instability. A definite minimum in the calculated total dissipation (for the whole star) occurred for each of two (L, M) pairs as the equilibrium radius was varied across the Cepheid domain. Assuming pulsations to occur at these minima permits one to derive a theoretical period-luminosity relation. The computed curve has a 3 or 4% greater slope than the empirical curve and is displaced, for given luminosity, toward longer periods by about 30% for a helium/hydrogen ratio (by numbers) equal to 0.10 and by about 60% for a helium/hydrogen ratio equal to 0.15. Efforts have been initiated to test some of the predictions of the linearized theory by use of the nonlinear, nonadiabatic code developed by A. N. Cox *et al.* at the Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

$H\beta$ Photometry of the Pleiades. D. L. CRAWFORD AND J. C. GOLSON, *Kitt Peak National Observatory, Tucson, Arizona*.—Photoelectric measures of the $H\beta$ line intensity have been obtained for the Pleiades members earlier in spectral type than G0. These measures show a good correlation with absolute magnitude. The rms deviation of the 19 B-type members, about the least-squares best-fit curve, is ± 1.9 mag. A comparison is made with the Hyades moving cluster as a check on the calibration. The present calibration for the late B-type stars fits the previous one for the Scorpius-Centaurus association (Hardie and Crawford, *Astrophys. J.*, in press) to within the observational error.

The Penumbra Filaments as Convection Rolls. ROBERT E. DANIELSON, *Princeton University Observatory, Princeton, New Jersey*.—Linearized equations describing the onset of convection in a horizontal layer of conducting fluid in the presence of a magnetic field have been derived by Chandrasekhar (*Phil. Mag.* 43, 501, 1952). From these equations growth rates of convection cells (of various sizes and shapes) have been calculated as a function of the magnetic field and the Rayleigh number for two cases: (1) a vertical magnetic field and (2) a horizontal magnetic field.

The penumbral filaments are long narrow structures having a width of 300 km or less and a length of 5000 km or more. Their lifetime is roughly five times that of the granulation. It is proposed that most of these filaments can be explained as convection rolls (i.e., long narrow convection cells) with the axis of the roll parallel to the horizontal component of the sunspot magnetic field.

The growth rate of convection cells in a magnetic field of 10 gauss or less (corresponding to the granulation) is compared with the growth rate of convection rolls in a magnetic field of 1000 gauss (corresponding to the penumbral filaments). The growth rate of the rolls is less than, but comparable to, the growth rates of the cells if the effective Rayleigh number in the penumbra is equal to the effective Rayleigh number in the granulation. The growth rate of the rolls will be five times less than the growth rate of the cells if the effective Rayleigh number in the penumbra is only a factor of 2 or 3 smaller than in the granulation. Hence it appears that both the lifetime and shape of the penumbral filaments can be accounted for by convection rolls.

Local Doppler Effects in the Photosphere. JOHN W. EVANS AND HORST MAUTER, *Sacramento Peak Observatory, Sunspot, New Mexico*.—High-resolution spectrograms taken under conditions of good seeing at Sacramento Peak show the charac-

teristic Doppler distortions of the solar Fraunhofer lines due to photospheric turbulence. The studies of Richardson and Schwarzschild (1950), Plaskett (1954), Goldberg, Mohler, Unno, and Brown (1960), and others, have fixed the directly resolvable dimensional characteristics and velocity distribution of the turbulent elements. This note reports the result of a first effort to determine the time variations. It is based upon a series of 31 spectrograms of the FeI line, $\lambda 5324.2$, taken at 20-sec intervals, and a 2-hr motion picture of the lines of FeI and CrI between $\lambda 5327.5$ and $\lambda 5329.5$, taken at a rate of 12 frames per minute.

Isophotometer tracings of the 31 spectrograms yielded curves of velocity as a function of position in the solar image along the spectrograph slit. The mean length of a turbulent element along the slit was $3.1''$, while the smallest element observed was $1.2''$. The rms velocity in this small sample varied between 0.25 and 0.4 km/sec. The distribution of durations of individual velocity peaks, during which they develop and decay, is still uncertain, since a number of the larger peaks persisted throughout the 10-minute interval of observation. Longer observing intervals, with attention to the rotational motion of the solar surface past a fixed slit, will be necessary for a definitive result. The present observations, however, showed a marked positive correlation between the maximum velocity attained and the duration of a peak. The smallest duration observed with any confidence (with due regard for the uncertainties of guiding and seeing variations) was about two minutes, with a peak velocity of $+0.5$ km/sec.

The motion pictures show the velocity fluctuations under rather mediocre seeing, and convey the impression of random velocity changes at any one point along the slit, with characteristic times of the order of three minutes. There were a few instances of a rather definite oscillation at one point between positive and negative velocities, going through as many as three complete cycles, with periods of about five minutes. Whether or not these are simply chance occurrences remains to be determined by a statistical study.

Positions of 517-Megacycle Solar Bursts. ROBERT FLEISCHER AND MASAKAZU OSHIMA, *Observatory of Rensselaer Polytechnic Institute, Troy, New York*.—A 517-Mc swept-lobe interferometer has been placed in operation at the Sampson Station of the Observatory of Rensselaer Polytechnic Institute. The spacing of the elements is 200 feet, giving a lobe spacing of 32.7 minutes of arc on the meridian. The fringe pattern is moved forward at the rate of 30 fringes per second, linearly with time. As the sun moves across the sky, a phase recorder indicates in a saw-tooth pattern the position between the lobes

occupied by the "center of gravity" of the radiation from the sun. The total intensity of the solar radiation is also recorded.

When a solar burst occurs, the center of gravity of the radiation moves to the east or west dependent on the location of the burst. The amount of the shift can be measured to an accuracy of 1 or 2 minutes of arc.

Preliminary results for seven burst events between August and November are presented and discussed. The location of the sources of the 517-Mc radiation are found to be consistent with the positions of the associated optical flares.

The time resolution of the present recording equipment permits the detection of angular motion for type-IV bursts in which the 517-Mc radiation is present for times of the order of a minute or more. Of the four type-IV events discussed, two were located near the center of the solar disk and showed no detectable angular motion. Of the two near the western limb, one was of low intensity, and the motion, if any, is inconclusive.

The source of the type-IV burst at 1510 UT on November 27 remained stationary for 4.6 minutes, and then began to move outward with a projected motion of 2600 km/sec which was observed for more than one minute of time.

Evaluation of Mica-Window Image Tubes. W. K. FORD, JR., *Department of Terrestrial Magnetism (Carnegie Institution of Washington)*, L. W. FREDRICK, *Lowell Observatory*, JOHN S. HALL, *Lowell Observatory*, T. E. HOUCK (Presently at the Imperial College, University of London), *Washington Observatory*, AND W. A. BAUM, (Guest Investigator—Lowell Observatory, June 1959–January 1960), *Mt. Wilson and Palomar Observatories*.—Since June, 1959, image tubes having mica-window outputs, made by ITT Laboratories for the Carnegie Image Tube Committee, have been tested at the Lowell Observatory.

In these tubes the phosphor screen was deposited on a circular mica window 14 mm in diameter and 8μ thick. With the aid of a mandrel, machined and polished to the curvature of this output window, it is possible to provide close contact between the mica and the emulsion of a photographic film. The measured resolution is close to 30 line pairs per millimeter on Kodak Plus-X film over an area 5 mm in diameter. Such resolution appears comparable to that of hypersensitized 1-Z plates but is about half that of 103a-O emulsions.

Several electrostatic tubes with S-1 cathodes have been used on the spectrographic equipment designed by Ford, and attached to the 24-inch Morgen telescope. More than 400 test or observational exposures were made by Fredrick with one tube without any

detectable change in tube characteristics. When the tubes are cooled with dry ice, exposures of one hour at $16\frac{1}{2}$ kv can be made which show very little background of internal origin.

The gain over unaided photography in the region from 0.9 to 1.1μ is at least 500. Above 1.1μ the effective gain has not been evaluated because comparative spectra of stars have not been obtained by unaided photography. Because of its relatively poor resolution in the blue, the effective gain of a tube with an S-11 cathode over unaided photography is only about ten.

The chief drawback of these electrostatic tubes is their small area of sharp focus. Recently, magnetically focused slotted-window tubes which have good focus over a distance of 35 mm have been made at ITT Laboratories.

This work was supported in large part by a grant from the National Science Foundation to the Carnegie Institution of Washington.

The Spectra of Planetary Nebulae and Stars in the Near Infrared. L. W. FREDRICK, *Lowell Observatory, Flagstaff, Arizona*.—Spectra of five planetary nebulae and selected late-type stars have been obtained in the $1\text{-}\mu$ region at dispersions of 109 A/mm and 61 A/mm at the phosphor of a mica-window image tube.

Planetary nebulae in general have been found to show only the 10830 line of helium. However, on our spectra NGC 7027 shows $P\gamma$, δ , ϵ S[III] (9532 A) and a few unidentified lines. Estimates of the relative strengths of these lines are given.

In the region of 10670–11000 A the spectra of the late-type—and especially carbon—stars present many new line or band features. The carbon stars show 36 lines or bands in the infrared region where 10 had previously been reported (McKeller 1954). One of these 36 lines, present in all late-type stars, is the SrII 10915 line predicted for M- and S-type stars by Keenan (1957). A number of stars show emission changes in strength from night to night, especially a line at 10870 close to the CN band head at 10876.

A few spectra have been taken to the redward of 1.1μ . Of interest are the two Na lines at 11381 and 11404 which are imbedded in the φ water-vapor band. An unidentified band-like feature occurs at 12570 A in Mira.

This work has been supported in part by a grant from the NSF to the Carnegie Institution of Washington.

Proposed Observations of Polarization and Interstellar Reddening from above the Ozone with High-Altitude Balloons. THOMAS GEHRELS, *Indiana University*.—The polarization of Venus, Mars,

and the moon increases strongly towards the ultraviolet (Gehrels, *Lowell Obs. Bull.* 4, 300, 1960), probably due to scattering either by molecules or by very small particles. It is proposed to extend the intercomparison of Venus, Mars, and the moon, with polarization measures down to 2000 A. The earth as a planet, observed from a high-altitude balloon, would also be included in the intercomparison.

The wavelength dependences of interstellar reddening (Whitford, *Astron. J.* 63, 201, 1958) and interstellar polarization (Gehrels, *Astron. J.* 65, 470, 1960) can be interpreted with the Mie theory, using calculations made by van de Hulst, and particles with diameters of about 0.3μ are inferred. However, no firm distinction between metallic and dielectric particles has as yet been made. Also, there are conflicting theories that explain the observations in terms of scattering by ions or by particles much smaller than 0.3μ . Measures at 2200 A, of stars at different galactic longitude, may be decisive because of the peculiar wavelength dependence predicted by the Mie theory.

The absorption in the earth's atmosphere between 2000 and 3000 A is due to ozone which, however, is mostly below 110 000 ft altitude (Goldberg, *The Earth as a Planet*, edited by Kuiper, Chap. 9; Epstein and Adel, *Arizona State College Rept.* HA-9, 1956). The limiting magnitude of our photometer and integrators (Gehrels and Teska, *Publs. Astron. Soc. Pacific* 72, 115, 1960) with a 36-inch telescope on the ground is near 14.0 mag. About a dozen fifth-magnitude stars, of early spectral type, would be easily observable with the proposed 8-inch telescope mounted in the gondola wall.

Observations at 2200, 2850, and 3250 A are planned for a series of flights above 110 000 feet, using 10⁷ cu ft balloons. With support from the Office of Naval Research, an orientation flight was made in July 1960, and the photometer is now being modified and tested at 2200 and 2850 A.

Decay Intervals of Extinct Radionuclides in Meteorites and in the Earth. GORDON G. GOLES, Graduate Student AND EDWARD ANDERS, Ph.D., Associate Professor of Chemistry—*Enrico Fermi Institute for Nuclear Studies and Department of Chemistry, University of Chicago*.—Iodine abundances in chondritic meteorites were determined by neutron activation analysis. From these data and information on meteoritic xenon published by Reynolds, I^{129} - Xe^{129} decay intervals for several meteorites (97 million years to ≥ 190 million years) and for the earth (≥ 210 million years) were calculated. A dating method based upon the Pu^{244} spontaneous-fission decay to Xe^{136} is proposed, and a Pu - Xe decay interval of 290 million years is calculated for the earth, indicating that the earth formed nearly 200 million years later than the meteorites. Possible

sources of the variations in these decay intervals are discussed.

It is suggested that a new dating method, similar to the Pb^{207} - Pb^{206} method and based on the two decay systems I^{129} - Xe^{129} and Pu^{244} - Xe^{136} , could be used to determine initial solar-system ratios of I^{129}/I^{127} and Pu^{244}/U^{238} , which would provide crucial tests of models of nucleosynthesis and the formation of the solar system.

The Critical Inclination Case of the Satellite Motion. YUSUKE HAGIHARA AND YOSHIHIDE KOZAI, *Smithsonian Astrophysical Observatory, Cambridge, Massachusetts*.—If the inclination of a satellite referred to the equator of the planet is near $63^{\circ}4'$, usual methods of successive approximation to solve the equations of motion fail because of a small divisor. However, it is shown that for this case the motion can be solved as functions of Jacobi's elliptic integral by applying the general theory of libration in the motion of asteroids and natural satellites.

If $J_2 + J_4$ is positive (J_2 and J_4 being coefficients of the second and the fourth harmonics in the potential), the pericenter of the orbit librates around either of its nodes, ascending or descending, which correspond to two of the four double points of the Hamiltonian. The motion near the other double points situated at the middle points of the two nodes is one of revolution or asymptotic at the double points.

If $J_2 + J_4$ is negative, the motion of the pericenter is of revolution or asymptotic near the former double points, and is of libration around the latter. By adding the third harmonic of the potential positions of the double points will be shifted a little.

A full text of the present paper will be published in *Smithsonian Contrib. Astrophys.* 5, No. 6.

The Helium Flash in Population II Giants. R. HÄRM AND M. SCHWARZSCHILD, *Princeton University Observatory*.—The evolution of a star of 1.2 solar masses has been followed through the phase in which the helium burning begins, with the following results. The helium burning sets in when the temperature in the contracting core reaches about 80 million degrees. Owing to the high degeneracy in the core the new energy source does not cause an expansion but rather heating. The rise of the temperature further accelerates the helium burning and thus a thermal runaway occurs, as predicted by Mestel. This runaway terminates only when the core becomes nondegenerate. Subsequent helium burning causes rapid expansion and cooling.

At the peak of the helium flash the temperature reaches approximately 300 million degrees. The energy liberated at this peak corresponds to about 10^{12}

solar luminosities. Practically none of this energy penetrates the thermal blanket of the nondegenerate outer layers of the helium core. The evolution at the peak is so fast that the time interval between successive numerical models had to be reduced to as low as 2 sec. It appears uncertain whether the neglect of dynamical effects remains a reasonable approximation in this phase.

In the Hertzsprung–Russell diagram the star slides down the red-giant branch while the helium flash goes on in the interior.

The Radio Spectrum of Supernova Remnants. DANIEL E. HARRIS, *California Institute of Technology*.—Thirteen galactic radio sources, tentatively identified with supernova remnants, have been observed at 960 Mc. The resulting integrated intensity measurements together with results of other observers at various frequencies have been used to compute spectral indexes.

One of these sources, the Cygnus Loop, has been observed at Manchester at 408 Mc with a beam-width nearly equal to ours. From a detailed comparison of these results, we find that all parts of the Cygnus Loop have essentially the same spectral index, in spite of significant intensity variations of the optical and radio emission.

Optical observations of the Cygnus Loop are used to compute an expected radio emission from electron-proton collisions. These calculations suggest that less than 2% of the observed radio intensity is due to free-free emission.

Distances of the remnants and corresponding diameters are estimated from the assumption that the physical size of thin filaments and small knots is the same for all objects. The spectral index is then found to be a function of the diameter of the remnant, and we suggest an evolutionary effect of radio spectrum flattening with age.

Neutral Hydrogen in the Magellanic Clouds—A Repeat Survey Using a Multichannel Receiver and Digital Recording. J. V. HINDMAN, R. X. MCGEE, A. W. L. CARTER, AND F. J. KERR, *CSIRO, Radio-Physics Laboratory, Sydney, Australia*.—We have recently combined a pilot experiment in digital data recording with a survey of the neutral hydrogen in the Magellanic Clouds. Observations were made at meridian transit at intervals of 1° in declination, with a $2^{\circ}2'$ aerial beam and a 48-channel H -line receiver. The output from each channel was recorded in cyclic binary code on punched paper tape, and also on a conventional Speedomax chart, at the rate of one profile every two minutes.

The center frequency of the receiver was crystal-controlled at a value equivalent to a radial velocity of +217 km/sec, with an accuracy of ± 0.02 km/sec and the channels were positioned at intervals of 7 km/sec, with individual bandwidths of 8 km/sec.

In the analysis of the records, the zero level and sensitivity calibration were established before and after each run for all channels. The ability of the digital methods of analysis to handle a great amount of tedious reduction automatically has made it possible to do some additional smoothing after recording, to increase the effective sensitivity.

The preliminary results corroborate the 1954 observations of Kerr, Hindman, and Robinson, as to the angular extent of the neutral hydrogen of the Clouds and the estimates of the mass of gas. In addition, the presence of a bridge of hydrogen, covering the area between the Clouds in the declination range from -72° to -76° , has been revealed, using the smoothing methods mentioned previously. In this case, the integrating time was effectively increased to 16 minutes and the effective bandwidth to 40 km/sec giving a sensitivity better than 0.1°K .

A feature of the observations is the "steep" leading and trailing edges of the emitting area of the Clouds at right ascensions of about $00^{\text{h}}30^{\text{m}}$ and $06^{\text{h}}15^{\text{m}}$, respectively.

The peak radial velocity distribution was characterized by the striking simplicity of arrangement—two large regions of positive velocity occurred in low and mid-galactic latitudes with negative velocity areas between. The galactic polar caps down to $|b| \sim 40^\circ$ showed a great predominance of negative velocities. Part of this pattern is due to differential galactic rotation but two definite facts emerged from the observations: Hydrogen is flowing outward in the directions of the center and anticenter in the low and medium latitudes and is streaming in from above and below in latitudes $|b| = 90^\circ$ to $\sim 40^\circ$. The maximum radial velocities involved in these motions are ± 12 km/sec. The complete flow pattern could not be determined from the present investigations. The average rate of inflow in high latitudes was estimated very approximately as $1 \times 10^{-7} M_\odot$ per square parsec per year.

A Short Note on the Two Fixed Center Problem in Three Dimensions. GEN-ICHIRO HORI, *Yale University Observatory, New Haven, Connecticut*.—The classical result of the two fixed center problem in two dimensions is easily extended to the three-dimensional case. The result is applied to the motion of an artificial satellite under the gravitational field due to Vinti's potential. The reducibility of Vinti's potential to the two fixed center problem was suggested by Dr. Pines.

Observational Evidence and Proposed Test for the Mode of Star Formation. SU-SHU HUANG, *Institute for Advanced Study, Princeton, New Jersey*.

—It is a well-known discrepancy that the fainter stars in new clusters, observed by Walker and by others, cover in the color-magnitude diagram a wide band above, but roughly parallel to, the main sequence, while the theory of gravitational contraction of premain-sequence stars would predict a single locus slanting away from the main sequence toward the low-temperature region in the H-R diagram (Walker, M. F., *Astrophys. J. Suppl.* 2, 365, 1956; Sandage, A. R., *Stellar Populations*, p. 149, 1958; v. Hoerner, 1960). In spite of a recent study by C. M. Varsavsky (*Astrophys. J.* 132, 354, 1960), who has tried to explain this discrepancy by the fact that the colors of these stars do not give reliable effective temperatures, we have found that the disagreement between theory and observation persists. Therefore, in order to understand the formation of the star and the evolution before its reaching the main sequence, we should search for, and study the distribution of, the infrared stars.

By assuming (1) a mass ($\mathcal{M}$)-radius, (R)-luminosity, (L) relation for the gravitationally contracting stars of the form

$$L = \mathcal{M}^\alpha / R^\beta,$$

with $\alpha = 4.6$ and $\beta = 0.79$ (Heney, L. G., LeVier, R., and Levée, R. D., *Publ. Astron. Soc. Pacific*, 67, 154, 1955); (2) E. E. Salpeter's empirical law of the distribution of stellar masses $d\mathcal{M}/\mathcal{M}^{1.35}$ (*Astrophys. J.* 121, 161, 1955); and (3) a uniform rate of star formation we have found that the premain-sequence stars are mainly distributed in the region of low effective temperatures, contrary to our usual understanding that the gravitationally contracting stars are dominantly located near the main sequence—an understanding which is true only for the unrealizable case of β approaching zero. Thus, if the star indeed is contracted from a condensation of huge extent, we will necessarily find a large number of infrared stars, say in the Orion nebula, or even in the solar neighborhood. Conversely if not many infrared stars were found in the search, we may have to introduce some new conception in the theory of star formation and in the early phase of stellar evolution.

Least-Squares Tables for Visual Binaries. JOHN B. IRWIN, *Goethe Link Observatory, Indiana University*.—In principle, a least-squares solution of a visual binary orbit should automatically and impersonally yield the best values of the elements of the orbit. This method, however, is seldom employed because it is so laborious; and this is so primarily because of the lengthy calculations necessary to eval-

late the differential coefficients appearing in the equations of condition. For example:

$$\frac{\partial \theta}{\partial e} = \left\{ \frac{57.3 \sin v (2 + e \cos v)}{1 - e^2} \right\} \{1 - \sin^2 i \cos^2(\theta - \Omega)\} = \alpha \cdot \beta,$$

where v is the true anomaly. Although $\partial \theta / \partial e$ is a function of four parameters, namely, e , v , i , and $(\theta - \Omega)$, it is possible to tabulate two functions, α and β , whose product gives $\partial \theta / \partial e$. α is a function of only e and M (the true anomaly) and β is a function of only i and $(\theta - \Omega)$. e , M , i , and $(\theta - \Omega)$ are known at each point so that the evaluation of a single value of $\partial \theta / \partial e$ involves two table lookups and one multiplication—a matter of a minute or less.

The other differential coefficients can be treated in somewhat similar fashion. A total of 11 tables suffices and these tables have been calculated with the IBM 350 at the Indiana University Research Computing Center. In a typical case, the use of these tables enables the computer to calculate and check all necessary coefficients in a matter of a very few hours. The tables can also be used to correct the elements one at a time.

Tables of $\partial X / \partial e$, $\partial Y / \partial e$, $\partial X / \partial M$, and $\partial Y / \partial M$ have also been calculated. Such tables are useful in the least-squares solution involving x and y rather than ρ and θ .

Reliability Approach to Astronomical Satellites.

EDWIN D. KARMIOŁ AND JOHN S. YOUTCHEFF, *General Electric Company, Missile and Space Vehicle Department, Philadelphia, Pennsylvania*.—As in all complex systems, astronomical satellite reliability is essential in the attainment of the operational objectives. However, the uniqueness of astronomical observations in space imposes reliability considerations and requirements which are equally unique. In determining the adequacy of the astronomical satellite to meet these requirements satisfactorily, techniques can be employed to predict the system reliability utilizing methods developed in ballistic missile and space vehicle reliability programs. This paper discusses the astronomical satellite operational and environmental problems and the techniques that can be employed to predict the probability of successful system functioning in the operational environment.

A New 21-cm Interpretation of the Spiral Structure and Motions of the Galaxy.

F. J. KERR, *CSIRO Radiophysics Laboratory, Sydney, NSW, Australia*.—A detailed comparison has been made between the Leiden and Sydney 21-cm surveys for the two halves of the Galaxy. The first reduction of the observations was done in a homogeneous manner, using the Leiden rotational velocity model for the whole Galaxy. This yielded a quite implausible

spiral structure diagram, and it was necessary to consider alternative models. As a basic criterion, the assumption was made that the structure and motions of the Galaxy are symmetrical on a large scale.

The observations for the southern side lead to somewhat lower apparent rotational velocities than are observed on the northern side. The results on the two sides of the Galaxy can be reconciled by introducing an additional solar motion component of 7 km/sec in a direction outwards from the galactic center, in other words, an outward motion of the young stars which are mainly involved in the determination of the "local center of rest." (This motion is relative to very distant hydrogen, and so the result is not in conflict with optical results on the solar motion relative to nearer objects.) A further anomaly is found in the asymmetrical appearance of the 21-cm relief map of the galactic disk, when based on the earlier model. This result, together with the lack of relative motion between the local stars and local gas, suggests that the gas at the sun's distance from the center is also moving outwards with a velocity of 5–7 km/sec. This motion is presumably related to the rapid outflow of gas which is known to be occurring in the central region.

A new spiral diagram has been derived, taking both rotation and expansion into account; the arms are more continuous and the general pattern has a more reasonable appearance than in earlier interpretations. Some of the implications of the proposed velocity picture will be discussed.

Star Distribution in the Globular Cluster M15.

IVAN KING, *University of Illinois Observatory*.—Star counts and photoelectric surface photometry have been combined to derive the star distribution in the globular cluster M15, from the small central core to the edge of the cluster. Because of its high central concentration, M15 is a severe test for any empirical law. The core has a radius of ten seconds, while cluster stars are easily detectable 15 minutes from the cluster center.

A plot of the logarithm of projected density against $\log r$ shows clearly that no power law will represent the distribution. Instead it appears that the density approaches zero at a finite value of r , exactly as should be expected for a cluster in the tidal field of the Milky Way. From $r=1'$ out to the limit of the observations, the projected density in M15 is closely proportional to $(1/r - 1/r_0)^2$. Extrapolation gives for the tidal limit of M15 $r_0=21'$, a figure which agrees well with the theoretical estimate. The formula also closely represents the densities outside the central cores in Centauri, 47 Tucanae, and M13, provided suitable values are taken for r_0 .

In the neighborhood of the limit, the above formula goes to zero as $(r_0 - r)^2$. This can be shown to

be a necessary consequence of the relaxation process in the cluster. Also, when r_0 is large this formula becomes the same as Hubble's law for the outer parts of spherical galaxies.

No attempt has yet been made to modify the formula to represent the leveling off of density in the central parts. However, it appears possible to do this by introducing one more parameter, to express the central concentration of the cluster. If this turns out to be so, it will be possible to represent the radial density distributions in all globular clusters by a single formula, and except for scale factors the differences between distributions will be given by a single concentration parameter.

The Dynamics of the Pleiades Cluster. D. NELSON LIMBER, *Yerkes Observatory, Williams Bay, Wisconsin*.—An estimate for the total stellar mass of the Pleiades is obtained through the application of an extended form of the virial theorem that takes account of the intracluster gas and dust. Published observational data have been taken as the sources for the required estimates for the relative spatial distribution of the stars and for the relative spatial distribution and total mass of the intracluster neutral hydrogen. With the results so obtained, the larger problem of the evolution of the cluster is examined in some detail. Conclusions are drawn concerning the luminosity function, the mass-spectrum, and the detailed dynamical state of the cluster.

The Distribution of Local Hydrogen from a 21-cm Multichannel Survey of the Sky. R. X. MCGEE AND J. D. MURRAY, *CSIRO Radiophysics Laboratory, Sydney, Australia*.—The whole sky visible from Murraybank, (lat. $-33^\circ 75'$), near Sydney, has been observed with a multichannel 21-cm hydrogen-line receiver and a widebeam aerial (2'2 between half-power points). From sample reductions of H -line profiles the disposition of local neutral hydrogen is presented in terms of three schematic diagrams: The distribution in N_H , the number of hydrogen atoms in a line-of-sight column of 1 cm^2 section, a diagram of representative line half-widths and the observed distribution of profile peak radial velocities.

Indications have been found that the gas has a general horizontal stratification in which regions of excess density occur. Its arrangement in space does not appear to be correlated with the so-called Local System but may have some connection with the local galactic magnetic field. Assuming the form of the distribution with z given by Schmidt, half-thickness 220 parsecs, an estimate of the density near the sun is $1.0 H$ atoms cm^{-3} .

The line profiles away from the Milky Way were generally single peaked with a range 12 to 35 km/sec

in half-width. Wide profiles of half-widths 36 to 140 km/sec were consistently observed in large regions near the galactic poles. Large-scale grouping of profiles in the comparatively narrow range 12–20 km/sec occurred corresponding closely with the outstanding features of the N_H distribution. This fact pointed to the compact nature of such large local complexes as the Scorpius-Ophiuchus spur and the Taurus-Orion region.

The Latest Cycle of the Be Shell Star β Mon. DEAN B. McLAUGHLIN, *University of Michigan, Ann Arbor, Michigan*.—This star is one of the brightest actively changing Be shell stars. Variation of V/R type is conspicuous, with a period of about 12.5 years. The hydrogen-emission lines, about 5 Å wide, oscillate in the same direction and with practically the same amplitude as the central absorption lines. As in other V/R variables, greatest positive velocity occurs when the violet emission component is strongest.

In previous cycles (McLaughlin, D. B., *Astron. J.* 56, 44, 1951) the velocity range was from about +3 to +45 km/sec. During the latest cycle the amplitude was greater, the maximum being +60 km/sec. Throughout much of the rising branch of the curve from 1952 to 1956, the shell absorption was greatly weakened, repeating the behavior in the previous cycle. Velocities of the absorption lines became systematically discordant. The first line to shift positively was $H\delta$ early in 1954. In 1955 $H\gamma$ followed, but $H\beta$ lagged and the lines remained discordant until late in 1956, when they had recovered much of their usual great strength.

The K line of Ca II showed unusual behavior. From 1930 to 1952 it was evidently wholly interstellar, with velocity +20 km/sec. From early 1953 to 1955 its velocity appeared definitely higher, averaging +35 km/sec. Throughout 1956 and 1957 a conspicuous additional K line appeared with velocity +100 to +130 km/sec. Simultaneously $H\delta$, $H\epsilon$, and $H\zeta$ developed weak absorption components with similar velocities, while the strong main hydrogen absorptions were at about +60 km/sec. During 1958 these extra hydrogen lines were not seen, and the K line shifted toward accordance with the main hydrogen components. In 1959 and 1960 the K line was accordant with hydrogen near +50 km/sec.

The Radio Telescope of the University of Illinois. G. C. McVITTIE, *University of Illinois Observatory*.—The telescope is a transit instrument with a reflector fixed to the ground; it has been designed by George W. Swenson, Jr., and its construction is being financed by the Office of Naval Research. The reflector is a parabolic cylinder whose dimensions are 600 by 400 ft, the longer dimension running

N-S. The reflector surface has been made of graded earth covered with sheets of asphalt liner for erosion control; on top of this is a galvanized steel wire mesh. The focal length is 155 ft and the focal line runs along the underside of a catwalk 4 ft wide and 10 ft high which is supported on four wooden towers. The reflector, towers, and catwalk are complete. The feed elements consist of 276 conical log-spirals which are spaced along the underside of the catwalk. The operating frequency is 611 Mc and the beam-width is 20 minutes of arc. Mechanical rotation of the feed-elements about their axes is used to alter the electrical phasing and thus to change the direction of the beam in the meridian plane. The scanning capability is estimated to be 30° on each side of the zenith. The first program will consist of a survey of all radio sources in the accessible region of the sky. The survey will give the positions and the flux densities of the sources.

Structure and Evolution of Globular Clusters.

RICHARD W. MICHIE, *Berkeley Astronomical Department, University of California*.—A three-parameter distribution function in terms of energy and angular momentum and with a cutoff at the energy of escape is used to describe the structure of a spherical stellar system. The corresponding density distribution for a specific set of parameter values is obtained numerically and the result agrees very well with observations of 47 Tuc from one to 50 parsecs by Gascoigne and Burr.

In obtaining the evolution of a spherical cluster, the basic assumption is that the continuous evolutionary process can be approximated by a series of successive equilibrium states. Therefore, the distribution function is assumed invariant in form and the problem is the calculation of the changes in the three parameters after a time interval. This is done by taking three moments of the Boltzmann equation with the assumption of dynamical equilibrium during the interval of time. These moments are mass, the sum over all stars of the kinetic energy, and the sum over all stars of the angular momentum squared.

An evolutionary time step of three quarters of a billion years is obtained numerically with an IBM 650. The results show a flow of stars inward within one parsec from the center and an expansion beyond twenty parsecs. The core of the cluster (within 1.6 parsecs from the center) contracts. In the inner regions the mean-square velocity decreases, and beyond twenty parsecs the mean-square velocity increases. The isotropy of the distribution in velocity space increases in the inner regions and decreases for the outer sections. This result can be explained by a few stars suffering encounters and being thrown into orbits of high energy and low angular momentum.

X Rays from Collisions of Stars. S. N. MILFORD, *St. John's University, Jamaica, New York*.—Collisions of stars can occur with high relative velocity during the collision of two galaxies. At relative velocities of order 2000 km/sec the kinetic energy dominates the gravitational energy and the two stars can slice through each other without much distortion, giving two partial stars A, B, and a collision complex C. For simplicity, the case of a star sliced exactly into two hemispheres is considered. The radiation from the surface of one half of a model star is integrated to give the total radiation. The calculated luminosities range from 10^{10} suns (K dwarf) to 10^{14} suns (B star), while the wavelength of maximum photon emission is in the range 2.0 to 6.5 Å. It may be possible to observe this x radiation from satellites; for example, a half B star at 3 billion parsecs would give a flux of 10^{-2} reddened photons $\text{cm}^{-2} \text{sec}^{-1}$ above the earth's atmosphere. It is probable that the collision complex C will radiate much more strongly than the partial stars A and B. Also, the radiation will rapidly shift to longer wavelengths as A, B, C expand and cool.

The frequency of such energetic B-star collisions is difficult to estimate; by assuming a stellar population similar to that of our galaxy, it is estimated that such energetic B star collisions may occur about once per thousand years in a sphere of radius 3 billion parsecs. Collisions of stars in single galaxies within the same volume occur much more frequently, but most of these are not energetic enough to release comparable amounts of energy.

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The Structure of Virgo A. ALAN T. MOFFET, *California Institute of Technology, Pasadena, California*.—The Caltech variable baseline interferometer has been used to measure the east-west brightness distribution of Virgo A at a frequency of 958 Mc. The source is found to be complex, consisting of a core with a diameter of 0.6, contributing 50% of the total flux, surrounded by a halo with a diameter of 6.5. This confirms the recent observations made at 1420 Mc by F. Biraud, J. Lequeux, and E. Leroix (*Observatory* 80, 116, 1960), except that at the higher frequency they find the contribution of the core to be 60% and the halo to be somewhat larger in diameter. Observations of B. Y. Mills (*Australian J. Phys.* 6, 452, 1953) are consistent with a small-diameter component contributing not more than 25% at 101 Mc. This suggests that between 101 and 1420 Mc the flux density from the core varies less steeply than $f^{-0.35}$, while that from the halo varies approximately as $f^{-1.0}$.

The core source is presumably to be identified with the well-known jet extending from the nucleus of M87. In a separate observation, Bolton has found the radiation from the core to be $\gtrsim 3\%$ polarized at 958 Mc. At very much higher frequencies, the radiation from the core should dominate. However, existing measurements at about 8000 Mc require that the spectrum of the core becomes steeper above 1420 Mc.

Preliminary analysis of brightness distributions in 130 sources has shown that such a complex structure is quite common. Some sources contain a core plus a halo, while others display a double peaked structure resembling that of Cygnus A.

This work was supported by the United States Office of Naval Research.

Estimation of the Dispersion of Redshift for Field Galaxies. JERZY NEYMAN AND ELIZABETH L. SCOTT, *Statistical Laboratory, University of California, Berkeley 4, California*.—It is assumed that the redshift Z of a field galaxy at distance D is a random variable with expectation HD , where H is the Hubble constant, and with variance $\sigma^2 = E(Z - HD)^2$ independent of distance. The problem treated is the estimation of σ^2 using the values of redshift Z and of apparent magnitude m of field galaxies in a catalogue, that is, subject to selection. The theory developed assumes (i) a catalogue of field galaxies resulting from an effort to include all galaxies observable with given instruments; (ii) the galaxies in the catalogue are reliably classified into morphological types fine enough to ensure that the ease of observing any two galaxies of the same type depends on their apparent magnitude only. Working in Euclidean space, it is found that among catalogue galaxies of a fixed type: (a) the regression of Z on $x = 10^{m/6}$ must be linear, $E(Z|x) = Ax$; (b) the regression of $Y = (Z - Ax)^2$ on x has the form $E(Y|x) = \sigma^2 + Bx^2$. Here A and B depend on the type of galaxy; the actual shape of the two regressions may be vitiated if the classification of galaxies is not fine enough. The formula for $E(Y|x)$ implies that the estimation of σ^2 reduces to that of the intercept of a quadratic regression. Preliminary results using the data of Humason, Mayall, and Sandage indicate that σ^2 must be small.

Tidal Deformations and the Origin of the Moon. ERNST J. ÖPIK, *Department of Physics, University of Maryland (on leave from Armagh Observatory, Northern Ireland)*.—Results of a provisional survey of the ellipticities of lunar craters in selected areas of Kuiper's *Atlas* are discussed. The rms random ellipticity is found to be 0.070 near the center, 0.096 near the limb, and is probably due to oblique impact. Small preferential components of ellipticity are indicated and interpreted as possible after-effects

of past tidal deformations. Formulae for tidal-rotational deformations of line elements on an elastic nonresisting surface are given. The smallness of the preferential effects is in itself significant, without regard to their absolute value. They suggest that the craters were formed when the earth-moon distance was of the order of 30 000–50 000 km. The undamaged appearance of the craters except for impact erosion and flooding, and the absence of signs of major crustal deformations indicates that since crater formation the moon could not have been at a closer distance. From theoretical rates of accretion as based on probabilities of interplanetary collisions, possible modes of origin of the moon are discussed. If the pre-mare craters mark the end of a continuous process of accretion which built the moon, the observed small systematic deformations of the craters are only compatible with the moon having accreted from a cloud of fragments circling the earth in direct orbits at a distance of 5–8 earth radii or greater. The assumption of different processes for accretion of the moon and for the formation of pre-mare craters leads to improbable consequences. Only when the preferential ellipticities are discounted as due to other causes or to chance, is it possible to accept the alternative of the moon having accreted from interplanetary material orbiting the sun. Accretion must then have run simultaneously with tidal evolution following initial tidal capture, the pre-mare craters having formed at a distance of over 200 000 km from earth as the final stage of this accretion.

Free-Free Emission in the Radio-Frequency Range. LUDWIG OSTER, *Yale University Observatory, New Haven, Connecticut*.—Classical and quantum-mechanical calculations for the free-free emission (bremsstrahlung) of electrons in a completely ionized plasma are critically investigated. Avoiding altogether the sometimes misleading assumptions found in the literature, it is concluded that the several classical computations are in complete agreement with the quantum-mechanical approach. Numerical coefficients are derived for a Maxwellian distribution of electron velocities. It is shown that for temperatures below, roughly, 550 000°K the classical results can be safely used; however, for higher temperatures quantum corrections are required. Finally, examination of the problem of a cutoff of the ion's Coulomb potential shows that this cutoff can be neglected for all frequencies above the plasma frequency in the range where the refractive index is effectively unity.

Heating of the Solar Chromosphere, Plages, and Corona by Magnetohydrodynamic Waves. DONALD E. OSTERBROCK, *Institute for Advanced Study, Princeton, New Jersey*.—The energy carried upward by sound waves generated in the hydrogen

convection zone can be estimated as 3×10^7 erg/cm² sec, though the numerical result is highly uncertain because of its great dependence on the turbulent velocity field. The spectrum of this noise is a broad band with maximum near the frequency of 0.01 cps. The waves propagate in the so-called "fast" mode, and become increasingly magnetohydrodynamic in character as they run out through the chromosphere, because of the negative density gradient. Little if any energy is emitted by the hydrogen convection zone in the "slow" or "Alfvén" modes, and these modes are in addition strongly absorbed in the photosphere. The cross sections for collisions between neutral atoms and ions in the chromosphere are large, and as a result the dissipation of the fast-mode waves by the frictional damping mechanism is very small. The waves build up to shocks, and the dissipation of these shocks is the main energy source for the chromosphere. The dissipation of the shocks is worked out using a similarity principle, in a way analogous to the Brinkley-Kirkwood theory of the dissipation of pure gas-dynamic shocks. At great heights, where the magnetic field dominates, the shocks become weaker, the dissipation decreases, and the rays are refracted back downward toward the photosphere. However, at these heights collisions between shocks must be expected to feed some energy into the slow mode and Alfvén mode, and these modes then propagate straight up the magnetic lines of force, with essentially no weakening by refraction, and carry energy into the corona. The plages are regions of larger magnetic field, where the refraction and shock-collision effects are more important; in addition there probably is extra generation of noise in the hydrogen convection zone below them.

The Frequency of Double Galaxies in Clusters.

THORNTON PAGE, *Van Vleck Observatory, Wesleyan University, Middletown, Connecticut*.—Systematic identification of double galaxies on Palomar Atlas prints now underway at the Van Vleck Observatory is expected to provide statistical evidence of the manner of formation and stability of these systems. It is necessary, of course, to estimate and deduct the number of "optical pairs," a quantity that will vary widely with surface density of individual objects (e.g., in clusters).

The classical formula due to G. Polya (*Astron. Nach.* 208, 175, 1919) is generally used (Holmberg, E., *Lund Ann.* No. 6, 1937; Page, T., *Astrophys. J.* 116, 63, 1952) to argue that $N_2^*(m, S)$, the total number of observed pairs of magnitude less than m and of separation, S , is far greater than $N_2(m, S)$, the number expected on chance over the whole sky. Actually, the expected number in a limited area will deviate widely from the mean because of variation in the surface density, $n_1(m)$, the number of single

galaxies of magnitude less than m per square degree.

Applying Polya's formula for the probability that an individual galaxy in a random distribution will have its nearest neighbor between θ and $\theta + d\theta$ radians, $W(\theta) d\theta = 2n \sin\theta \cos^{2n-1}\theta d\theta$, one finds that the number of "unambiguous chance pairs" per square degree is expected to be

$$n_2(m, S) = \pi n_1^2(m) S \exp[-2\pi n_1(m) S^2].$$

Subtracting this from the observed surface density of pairs, we have the estimated number of physical pairs in a cluster, and, if spherical symmetry is assumed, the space density, $d_2(m, S)$. Allowing for the projection of space separation, R , into the projected angular separation, S , this yields the frequency distribution of R among double galaxies in a cluster.

Furthermore, $d_2(m, S)$ may be compared with the space density of individual galaxies in the cluster, $d_1(m)$. If the formation of physical pairs is due to capture, d_2 will be proportional to d_1^2 , a relation subject to observational verification, and the constant of proportionality is related to the velocity dispersion and past history of the cluster.

A Hydrogen-Line Interferometer. V. RADHAKRISHNAN, D. MORRIS, AND R. W. WILSON, *California Institute of Technology, Pasadena, California*.

—A new and promising technique for the study of interstellar 21-cm absorption has recently been tried at the Caltech Radio Observatory. The twin 90-foot paraboloids were operated in a narrow-band interferometer arrangement at 1420 Mc. The fringe pattern obtained with the antennas tracking a point source had an amplitude proportional to the "visibility" of the source within a 6-kc bandwidth at a frequency which could be continuously varied by tuning the second local oscillator.

An improvement in sensitivity over single-dish operation was obtained by virtue of the increased collecting area and the absence of switching. The real merit of the system, however, for absorption studies, was in that it made the difficult determination of the "expected" profile redundant. The emission from the extended hydrogen clouds was resolved out and the amplitude versus frequency pattern obtained was essentially the spectrum of the point source within the beam. It was possible, for example, to clearly detect an absorption feature at +4 km/sec in the spectrum of 3C-123, whose intensity is only one-fiftieth that of Cas A. Parametric or other low-noise amplifiers should bring a vast number of point sources within reach of such investigation.

The sources Cas A, Cyg A, Sgr A, and the Crab, Orion, and Omega nebulae were observed with the interferometer. In most cases there were small but significant differences from single-dish values in optical depths and/or linewidths. These differences

were not systematic, and indeed promise to throw additional light on cloud structure and temperature. At the antenna spacing used, only the center source of the Sgr A complex was unresolved by the interferometer and it was thus possible to study and compare the absorption in the spectrum of the center source with that of the complex source. Different baseline spacings and orientations (corresponding to resolution planes) should provide a valuable complement to the information obtainable with single antennas.

This work was supported by the United States Office of Naval Research under contract.

Infrared Isothermal Mapping of Certain Crater Areas of the Moon. J. M. SAARI AND R. W. SHORT-HILL, *Aero Space Division, Boeing-Airplane Company, Seattle, Washington*.—Detailed isothermal contour maps of relatively small areas of the moon which can be related to the visible surface features should prove valuable in deducing localized properties of the surface. To this end, measurements were made on a variety of crater areas with the 60-inch telescope at the Mount Wilson Observatory. The thermistor detector subtended a field of 8" (~ 10 miles on the moon's surface) when mounted at the Newtonian focus. A scan program was used which consisted of setting the clock near lunar rate and moving the telescope alternately east and west while the moon drifted in declination. The position of the detector on the moon was followed at the finder telescope and a description of its motion was recorded vocally on one channel of a tape recorder while the temperature signal was recorded simultaneously on the other channel.

During totality of the September 5, 1960 eclipse scans were made over the rayed craters Tycho, Copernicus, Aristarchus and Proclus; all except the latter proved to be about 40°C warmer than their surroundings. In addition, several drives across Kepler at the same time showed similar results. All of these areas were scanned during the full moon together with six other areas (Alphonsus, Cleomedes, Dionysius, Menelaus, Posidonius and Theophilus). In general, the infrared energy variations observed in these areas were comparable to those found over the rayed craters during totality, although the temperature differences are less because of the higher temperature. Explanations for the variations will be discussed in terms of geometry and localized variations in surface properties.

This work was supported by the Air Force.

The Abundance of Water Vapor on Mars. CARL SAGAN, *Dept. of Astronomy, University of California*.—To date, all spectroscopic searches for water vapor on Mars have been negative. A resulting rigid

upper limit on the water vapor abundance is 3.5×10^{-2} g cm $^{-2}$. A lower limit to the water-vapor abundance follows from the discrepancy of about 30 K° between the theoretical radiation temperatures and the observed thermocouple temperatures of Mars. The water vapor required in addition to the Martian CO $_2$ to explain this greenhouse effect is determined as a function of the mean infrared surface emissivity, ϵ . If $\epsilon < 0.82$ no water vapor is required; since observations of the polar ice caps indicate water vapor must be present, ϵ must exceed 0.82. The emissivity of Mars in the 3.5- μ surface absorption bands is 0.94. One minus the visual albedo is 0.85. The true infrared emissivity should fall between these values, as is characteristic of many common minerals. The resulting water-vapor abundance is between 2×10^{-2} and 2×10^{-3} g cm $^{-2}$. The H $_2$ O abundance can also be determined from the vapor pressure above the sublimating edge of the polar ice cap, if the temperature of the edge is known. Considering an increase over the theoretical temperature of the edge due to CO $_2$ alone, a water-vapor abundance is derived. A new temperature is derived from the CO $_2$ -H $_2$ O greenhouse effect. Successive approximations converge near 10^{-2} g cm $^{-2}$ for $\epsilon \simeq 0.90$. We conclude the water-vapor abundance is within an order of magnitude of existing spectroscopic tolerances. The corresponding thickness of the polar caps at maximum extent is about 1 mm. With 10^{-2} g cm $^{-2}$ of water vapor on Mars, there are few infrared wavelength intervals of complete transparency; with 10^{-3} g cm $^{-2}$, the 5- to 8- μ interval where characteristic organic bond resonances lie is almost completely transparent. Observations of this interval from high altitudes should give a firm water-vapor abundance determination. These low water-vapor abundances do not argue against life on Mars; obligate halophiles are known which obtain their entire water requirements from the water absorbed on a crystal of salt, and other organisms are known which produce all water requirements metabolically.

On the Origin of the Venus Microwave Emission. CARL SAGAN, *Dept. of Astronomy, University of California*, K. M. SIEGEL, *Radiation Laboratory, University of Michigan*, AND D. E. JONES, *Jet Propulsion Laboratory, Pasadena, California*.—The Venus microwave spectrum is thermal from 21 cm to 3 cm. Below 3 cm the conjunction brightness temperature falls from about 600°K to about 300°K at 8 mm. There are two possible sources of this emission: a Cytherean ionosphere, at an electron temperature of 600°K, which becomes optically thin below 3 cm; and a 600°K surface overlaid with clouds which attenuate only below 3 cm. A uniformly thick ionosphere in which free-free transitions reproduce the observed spectrum has $\int n_e^2 dz \simeq 4 \times 10^{25}$ cm $^{-5}$,

in the dark hemisphere. If the ionosphere is 100 km thick, the mean electron density is $n_e \approx 2 \times 10^9 \text{ cm}^{-3}$, a factor of 10^3 greater than in the terrestrial ionosphere. The ionospheric model gives a strong phase effect at 8 mm, and a negligible phase effect at 3 cm, in good agreement with observations at Lebedev Physical Institute and NRAO, but not at NRL. The required n_e in the illuminated hemisphere is 10^{10} cm^{-3} . Somewhat marginal Millstone radar data suggest a plasma frequency near 400 Mc; therefore also for the dark side $n_e \approx 10^9 \text{ cm}^{-3}$. However, electron densities of this order are very difficult to explain. If solar electromagnetic radiation is the source of ionization, recombination coefficients of the order 10^{-14} to $10^{-16} \text{ cm}^3 \text{ sec}^{-1}$ are required. Radiative recombination coefficients are characteristically $\sim 10^{-12} \text{ cm}^3 \text{ sec}^{-1}$ and dissociative recombination coefficients $\sim 10^{-8} \text{ cm}^3 \text{ sec}^{-1}$. There would seem to be no way of quenching radiative recombination and allowing lower rate processes, e.g., three-body collisions, to dominate. Solar corpuscular radiation can be the source of ionization only if the Cytherean magnetic field strength is below 0.03 gauss. Both the mean density of Venus and the observations of a decline in terrestrial magnetic activity during Cytherean inferior conjunction argue for fields ~ 1 gauss. The low surface temperatures required for the ionospheric model are inconsistent with the greenhouse effect implied by the observed abundances of CO_2 and H_2O . A definitive experiment to decide between ionospheric and surface origin—a scan of the Cytherean disk near 1 cm—is planned for the 1962 Venus probe.

The Ages of the Open Cluster NGC 188 and the Globular Clusters M3, M5, and M13 Compared with the Hubble Time. ALLAN R. SANDAGE, *Mount Wilson and Palomar Observatories, Pasadena, California*.—Observational data show that the main-sequence termination point occurs in the color-magnitude diagram at $M_{\text{Bol}} = +3.8$ for NGC 188, at $M_{\text{Bol}} = +4.15$ for M3 and M5 (Arp's data), and at $M_{\text{Bol}} = +3.85$ for M13. These values are obtained by fitting the main sequence of the clusters to that of the Hyades, after appropriate blanketing corrections are applied to the observed colors. Such corrections are indicated by the observed ultraviolet excess in the globular cluster stars, presumably caused by the weak Fraunhofer lines due to low metal abundance. The data for all four clusters also show the change in the slope of the main sequence from the breakoff point to 4 mag. fainter caused by the initial evolution from the age-zero main sequence. Even though the observed main-sequence breakoff point for the high metal content cluster NGC 188 occurs at the same M_v as for the low metal content cluster M13, Hoyle's evolutionary tracks (*Monthly Notices Roy. Astron. Soc.* 119, 124, 1959) show that the globular cluster

stars take longer to evolve to a given configuration. Using Hoyle's models, the ages of the clusters are computed to be 16×10^9 years for NGC 188, 22×10^9 years for M13, and 26×10^9 years for M3 and M5. These ages are long compared with the time available since the beginning of the expansion of galaxies according to model universes. In a universe with $\Lambda = 0$ and the deceleration parameter $q_0 = +1$ (as determined by the redshift and apparent magnitude measurements of Minkowski and Baum), the time since the beginning of the expansion is given by $t_0 = 0.57 H^{-1} = 7.4 \times 10^9$ years if $H = 75 \text{ km/sec } 10^6 \text{ pc}$. The only cosmological models which can "save the time scale" are the steady state universe or a generalized Eddington-Lemaître model with $\Lambda > 0$. However, both types of models require $q_0 = -1$ instead of the observed value of $q_0 = +1 \pm \frac{1}{2}$ (Baum, unpublished). All available data are therefore inconsistent. Changes in (1) the stellar evolutionary time scale, (2) the value of the Hubble constant, (3) the observational redshift-magnitude data, or (4) cosmological theory seem to be required at this point.

Hypersensitization Gains in the Near Infrared. NICHOLAS SANDULEAK, *Warner and Swasey Observatory, East Cleveland, Ohio*.—The hypersensitization of the Kodak 1-N emulsion by water, triethanolamine, and ammonia treatment was studied as part of a project aimed at increasing the effectiveness of objective prism detection of faint, cool stars.

Straightforward intercomparisons were made of optical densities for hypersensitized and for untreated spectroscopic plates which had been given identical exposures and development under controlled darkroom conditions. A tube-sensitometer was used to impress, in the course of a single exposure, a series of extended images of graduated density upon each plate. The optical density of each image was measured with a photoelectric densitometer and these data were used to construct characteristic curves. The displacement of the hypersensitized characteristic curve from that shown by the untreated emulsion, at a common density of 0.6, was taken as a measure of the gain in sensitivity.

The gain in sensitivity achieved by each of the methods was found to depend on the recipe used for the hypersensitizing solution, the age of the emulsion when treated, and the exposure itself.

Pre-exposure treatment of fresh plates with water, triethanolamine, and ammonia solutions was found to produce an average increase in speed of 2.1, 3.3, and 4.0 times, respectively. The results apply for objective prism photography in the spectral range $6800\text{\AA}$ to $8800\text{\AA}$. They are valid for exposure times of the order of 30 minutes and therefore for typical astronomical applications.

This project was sponsored by the National Science Foundation.

Spectrum of the Flare of September 2, 1960. ELSKE V. P. SMITH AND PATRICK S. MCINTOSH, *Sacramento Peak Observatory and Harvard College Observatory, Sunspot, New Mexico.*—We obtained at the maximum of this flare a spectrum that covers the entire range from $\lambda 3700$ to $H\alpha$. The peak intensities of the early Balmer lines, $H\alpha$ through $H\zeta$, are about two times the continuum level and decrease gradually to 10% above the continuum at $H12$. The last Balmer line that is clearly visible is $H14$. All the Balmer lines are exceptionally wide, starting with $H\alpha$ at 22 Å total width, $H\delta$ 16 Å, and $H11$ about 6 Å. The metal and helium lines, however, have considerably smaller widths, 4 Å for HeI D3 for instance, 5 Å for the $CaII$ K line, and only of the order of 1.5 to 2 Å for the NaI D lines and MgI b group. None of the lines show any indication of central self-reversal. All lines, whether due to hydrogen or metals, are asymmetric in the usual sense, namely the red wind falls off more slowly and extends further than the blue.

In several respects this flare seems similar to that of September 17, 1957 studied by Jefferies and the Smiths, and of July 30, 1958, studied by Z. Svestka. Here too a layer of high excitation but low opacity appears to cover a much more extensive region of lower excitation but very great opacity. The source function in such a model would increase sharply near the surface of the flare.

Meteor Observations with an Image Orthicon. I. JOHN SPALDING, *General Engineering Laboratory, Schenectady, New York*, AND CURTIS L. HEMENWAY, *Dudley Observatory, Albany, New York.*—An experimental system composed of an $f/1.1$, 2" focal length camera lens, a Z5294 G.E. image orthicon and associated electronics have been used to obtain pictures on a TV monitor of meteors, wakes, trains, aurorae, and faint clouds. Typical monitor photographs taken during the Perseid shower (August 12, 1960), are shown.

Meteor pictures with 1/30-sec exposure are found to effectively stop the meteor motion. The limiting magnitude of the system appears to be fainter than 6th magnitude for meteors.

Meteor wakes can be distinguished from meteor trains and the time and position development of both are available for study. The train phenomenon has been shown to take approximately $\frac{1}{2}$ sec to develop after the passage of a meteor and the lengths of trains are found to be significantly shorter than the observed meteor lengths.

Three train spectra were obtained in two hours' observation using an objective prism. While the

spectra have low resolution, they indicate that the train spectra are very narrow compared with meteor and wake spectra.

Auroral photographs have also been obtained at 1/30-sec exposure and motion pictures of time behavior in aurorae can be made.

The New University of Georgia Observatory. L. HAROLD SPRADLEY, JR., *Department of Physics and Astronomy, Athens, Georgia.*—In developing a program of teaching and research in astronomy, the University of Georgia is building an observatory on the main campus of the University at Athens. The principal instrument is a Newtonian-Cassegrain telescope of 24" aperture, built by the Fecker Company. Also in construction is an 8" camera with a focal ratio of $f/6.3$, to be housed separately from the main telescope. The research program will emphasize problems in optical resolution, particularly as applied to objects in the solar system, the first subject under consideration being the slopes of features on the surface of the moon.

A Spectrophotometric Comparison of 7 Sextantis and Sirius. YVONNE H. STONE AND GEORGE WALLERSTEIN, *Berkeley Astronomical Department, University of California.*—We have compared atmospheric parameters and abundances in the high velocity A-dwarf 7 Sextantis with Sirius. Both excitation temperature and the colors lead to the conclusion that θ (7 Sextantis) $-\theta$ (Sirius) $= -0.03 \pm 0.05$ (maximum error), and $\log P_e$ (7 Sextantis) $-\log P_e$ (Sirius) $= +0.08$. The measured equivalent widths combined with these parameters yield an iron to hydrogen ratio that is twice as large in 7 Sextantis as in Sirius, but the uncertainty in the temperature permits an equal abundance. Relative to iron Al , V , Ti , and Cr are normal; Mg , Si , and Mn may be overabundant by a factor of 2 or 3, while Sr may be deficient by a factor of 2 and Ba by at least a factor of 3. He lines $\lambda\lambda 4026$, 4388 , and 4471 are present indicating an excess of helium in 7 Sextantis, but the amount is exceedingly temperature sensitive. Carbon is overabundant by a factor of 10 if our identification of a line at $\lambda 4267$ as due to CII in 7 Sextantis is correct.

Use of Balloons and High-Altitude Aircraft for Precursor Satellite Studies. JOHN STRONG, *Laboratory of Astrophysics and Physical Meteorology, Johns Hopkins University, Baltimore, Maryland.*—High-altitude balloons and aircraft, available now, offer attractive possibilities to study the atmospheres of the earth, planets and stars.

This atmospheric absorption break-through by means of lighter- and heavier-than-air vehicles is

particularly attractive for those interested in observations to be made in the infrared spectrum. Astrophysical results obtained with satellite- or rocket-substitute vehicles, together with the means developed to obtain them, not only have intrinsic merit, but they have ancillary merit as precursor programs for more ambitious studies.

The observations from high altitudes that have been made with Johns Hopkins equipment, using a balloon platform to look at the earth and Venus, and using high-altitude aircraft to look at the sun, will be reviewed. The latter observations bear on the problem of water-vapor content in the upper air at high latitudes. Programs that are being planned for such vehicles, and their potential significance, will be discussed.

The B8 Component of β Lyrae. OTTO STRUVE, *National Radio Astronomy Observatory, Green Bank, West Virginia*.—1. In a recent paper Struve and Zebergs have determined the wavelengths of 299 absorption lines between wavelengths 3679 Å and 584 Å. The following elements and stages of ionization are either definitely or probably present: *H, HeI, CrI, Ni, NII, MgI, MgII, AlI, AlII, SiII, SiIII, SII, CaII, ScII, TiII, VII, CrI, CrII, MnI, FeI, FeII, FeIII, VII, SrII, ZrII*; the presence of *OII, AlIII, SeI, MnII*, and *YII* is uncertain. The presence of strong *HeI* lines and of fairly strong lines of *FeII* indicates an anomaly in the atmospheric composition of this star. Similarly, the presence in the same spectrum of *FeI, FeII*, and *FeIII* is indicative of an unusual state of ionization and excitation that may imply the existence of a stratified atmosphere. However, there is no evidence of differential motions.

2. Measurements of the equivalent widths of many absorption lines belonging to the B8 star were made near secondary minimum at which phase the B8 lines are relatively little affected by the lines of the shell or by the emitting layer. A comparison with measurements by A. A. Boyarchuk suggests that the abundance of *HeI* is less pronounced than was found at the Crimean Observatory. With the exception of some systematic errors depending upon the wavelength, the new equivalent widths tend to be somewhat larger than Boyarchuk's. Otherwise the agreement is satisfactory.

3. Observations made during the partial primary eclipse immediately following principal minimum indicated in 1958 that the so-called rotational disturbance was strikingly different in two successive cycles. A similar difference was found in the 1955 observations, also after mid-eclipse, in two cycles separated by about 26 days. At these phases the line of sight passes through the dense ionized gas of the approaching stream and it is reasonable to believe that the observed effect is caused by differences in the

electron scattering of the starlight within the approaching stream.

4. The Stark broadening of *HeI* lines that are not noticeably distorted by emission or shell absorption indicates an absolute magnitude for the B8 component of the order of possibly -3 or at most -4 . Hence, if the B8 star obeys the mass-luminosity relation the mass ratio of the system must be quite different from the one used previously and all the geometrical parameters of the system will have to be recomputed.

The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with NSF.

Numerical Integrations for Nonlinear Compression Waves and Line Profiles in Cepheid Atmospheres. R. G. TESKE, *The McMath-Hulbert Observatory of the University of Michigan*.—Numerical integration of the nonlinear equations for one-dimensional adiabatic flow has been carried out for a "real" Cepheid atmosphere, and line profiles predicted for several phases during a quarter cycle. This work is part of a program aimed at providing a basis for more critical interpretation of observed Cepheid line spectra, with particular emphasis on W Virginis and related objects. Calculations were done with Smithsonian Astrophysical Observatory's IBM 704 computer.

The model selected for the calculations consisted of a plane-parallel atmosphere initially in hydrostatic and radiative equilibrium, described by $\log g=1.0$, $T_{\text{boundary}}=4300^\circ$, with an opacity directly proportional to gas pressure; $\log g$, T_{boundary} and the constant of proportionality between opacity and gas pressure were kept constant during the gas-dynamic integrations. The equations for nonlinear flow were integrated assuming this initial configuration to be driven by a rigid, infinite piston (which lay initially at $\tau=10.0$) whose velocity was taken to be a sine function of time. The piston was given a period of 5.9 days and a small velocity amplitude of 5.5 km/sec. A shock front formed at optical depth $\tau=0.7$ about one day (8×10^4 sec) after the piston began to move upward; the integration was stopped when the advancing shock reached the depth $\tau=0.08$, after about one-quarter cycle of the piston.

Distributions of pressure and velocity in the wave were obtained as functions of time. Optical depths were computed on the basis of the assumption that as a volume element relaxes radiatively its pressure remains at the adiabatic value, and distributions of velocity in optical depth were derived for various times. These show that $(d/d\tau)|v|$, where v is outward velocity, can be quite large at the wave front prior to shock formation. After the shock discontinuity formed, velocity at "accessible" levels ($\tau \lesssim 1.0$)

is determined by the shock strength and can exceed the piston speed by a factor of 2 or more. A change of sign of the derivative of velocity with depth after a quarter-cycle is due to the outward-propagating rarefaction wave.

Absorption contours were computed at $\mu=1$ for lines of two strengths— $\log \eta_0=0$ and $\log \eta_0=1.6$ —at different phases. These show a progressive line doubling as the wave front advances; intensity ratios for the two components of each line may be quite different, and even reversed, between the weak line and the saturated line.

Calculations with similar models in which the line contours were integrated over the disk have shown (1) that weak shocks may be present without causing line doubling and (2) that the velocity differences between components are not closely related to shock strength, but depend upon the sign and magnitude of $(d/d\tau)|v|$.

The results of these calculations also provide a foundation for an observational distinction between the view that solar granules are produced by compression waves generated in the convection zone and the view that the granules are themselves the convective cells, through analysis of high-dispersion spectra procured with the vacuum spectrograph at the McMath-Hulbert Observatory.

Lunar Temperature Measurements at 8.6-mm Wavelength. WARREN C. TYLER AND JACK COPELAND, *Research Laboratory, Army Rocket and Guided Missile Agency, Redstone Arsenal, Alabama.*—Radio observations of the moon have been made at 8.6-mm wavelength using a conventional Dicke-type superheterodyne radiometer. The antenna is a horn-fed paraboloidal reflector five feet in diameter. The beam width is about 20 minutes of arc to half-power points.

Effective lunar disk temperatures were measured during the eclipse of September 5, 1960. At this longitude, moonset occurred at the beginning of totality, by which time a net decrease of about 20°K was observed.

Observations have also been made in order to determine the variation in effective disk temperatures as a function of lunar phase. The results obtained from these measurements are in substantial agreement with previous measurements at this wavelength.

The Clustering of Galaxies. SIDNEY VAN DEN BERGH, *David Dunlap Observatory, Ontario, Canada.*—A cluster of galaxies is usually regarded as a distinct type of aggregate of matter which is intermediate between the individual galaxy and the universe as a whole. The concept "a cluster of galaxies" would

lose much of its usefulness if it could be shown that most clusters can be divided into subclusters or even smaller units. Alternately, one may inquire if clusters of galaxies are the largest aggregates of matter or whether they are themselves constituents of still larger organizations.

Examination of the Local Group and of the Virgo cluster shows that subclusters exist within each of these systems. An analysis of the angular separations of the galaxies in the Coma cluster indicates a weak subclustering tendency. In fact, subclustering appears to be a quite general phenomenon, although it may be less pronounced in dense clusters like the Coma cluster than in low-density clusters like the Local Group. The existence of binary galaxies (LMC, SMC) and multiple galaxies (M31, M32, NGC 205) within the local group is well established. An analysis of the radial velocities of galaxies in the Virgo cluster also indicates the existence of stable binary systems.

The Lick counts of galaxies give strong evidence for the existence of clusters of clusters of galaxies with characteristic dimensions of the order of 10 mpc. There is also fairly good evidence that the "Local Group" belongs to a vast supercluster containing the Virgo cluster. Do still larger aggregates of matter exist? An analysis of the distribution of the most distant ($V \approx 50\,000$ km/sec) very rich clusters observed by Abell indicates that inhomogeneities with characteristic dimensions in excess of 100 mpc may exist.

The available evidence strongly suggests a hierarchy of clustering ranging from binary galaxies to clouds of superclusters of galaxies. The universe may well be much less homogeneous than has been generally assumed.

The Rayleigh-Taylor Instability in Compressible Fluids. PETER O. VANDERVOORT, *National Radio Astronomy Observatory, Green Bank, West Virginia* (now at *Princeton University Observatory*).—The Rayleigh-Taylor instability of an isothermal atmosphere supported against gravity by a uniform incompressible fluid has been analyzed. A perturbation characterized by a periodic deformation of the boundary separating the two fluids is found to grow like $\exp \eta$, and the dependence of the growth rate η on the wavelength λ of the perturbation is determined. For very short wavelengths, η is proportional to $\lambda^{-1/2}$ (as is the case for all wavelengths when both fluids are incompressible); whereas for long wavelengths η is proportional to λ^{-1} . Thus, the effect of compressibility is to retard the growth rates for the longest wavelengths. The transition from the $\lambda^{-1/2}$ -dependence to the λ^{-1} -dependence of η occurs in a range of wavelengths of order λ_c , where λ_c is a determinate quantity in the theory.

If the Raleigh-Taylor instability can occur at the boundary of an expanding HII region, the present model is a reasonable first approximation to the physical situation in the sense that compressibility is important mainly in the surrounding $H I$ region (the upper fluid). Since the growth rates of perturbations having long wavelengths are retarded, λ_0 is the order of the longest wavelength with which the Raleigh-Taylor instability is likely to be observed in an HII region. If the temperature of the HII region is $10\,000^\circ K$, and if the acceleration of the boundary of the HII region lies in the range 4×10^{-8} cm/sec² to 4×10^{-7} cm/sec², then λ_0 lies in the range 8 pc to 80 pc. These values are to be compared with the maximum observed widths of the order of 6 pc for the so-called "elephant trunk" structures which are found in HII regions.

The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

The Metal-Rich G-Dwarf 20 Leo Minoris and Two Comparison Stars. GEORGE WALLERSTEIN AND H. L. HELFER, *Berkeley Astronomical Department, University of California and Department of Physics and Astronomy, University of Rochester.*—We have found 20 Leo Minoris to be overabundant in 11 elements by a factor of 2 when compared with the sun. The uncertainties in the analysis admit the possibility that the overabundance is as small as that in the Hyades (25%) to as large as a factor of 3 greater than the sun. The low-velocity star HD 187923 has a slight excess of metals and the high-velocity star HD 30649 is deficient in metals by a factor of 2. Both HD 187923 and HD 30649 are deficient in manganese relative to the other ten elements studied.

On the Distribution of Electron Density Inside the Earth's Orbit. J. L. WEINBERG, *High Altitude Observatory, Boulder, Colorado.*—Photometric studies of the brightness and polarization of the zodiacal light have previously been used to obtain a maximum electron density, N_e , at the earth's orbit of approximately 600 cm^{-3} .

These results are re-examined in the light of recent zodiacal light observations and the maximum number density of electrons for various distances from the sun is found to be considerably lower than that previously determined. In one example N_e was found to be less than 100 cm^{-3} at 1 a.u.

Galactic Motions in a Large-Scale Magnetic Field. DONAT G. WENTZEL, *University of Michigan Observatory, Ann Arbor, Michigan.*—A large-scale galactic magnetic field transfers angular momentum of the interstellar gas among different regions of the

galaxy and thereby causes cumulative, rather than epicyclic, radial displacements of the gas. The persistence of spiral structure in spite of differential galactic rotation indicates that such a magnetic field exists. A plausible field connecting the galactic plane with the halo can exchange angular momentum between these regions and leads to two giant circulations of the interstellar gas on each side of the galactic plane. The observed radial motions of the "3-kpc arm" and the isolated central region of the galaxy can be explained adequately.

A Heavily Reddened Cluster in Ara. BENGT WESTERLUND, *Uppsala Southern Station, Mount Stromlo Observatory, Canberra, A.C.T. Australia.*—During a survey of the southern Milky Way with the 20/26-inch Schmidt telescope at Uppsala Southern Station a heavily reddened cluster has been found in Ara at R.A. = 16^h45^m3 , Dec. = $-45^\circ46'3$ (1960). The region shows some very dark lanes and a few emission patches. The brightest stars in the cluster are found at $V=14$ mag. No stars can be seen in the cluster region on plates reaching $B=19$ mag. From a preliminary photometry in infrared and visual light of 80 stars inside of circle of $2'$ in diameter a mean total visual absorption of 11.2 mag. has been found. The color-magnitude array indicates that the cluster is very young. It appears likely from the photographs that most of the absorption is caused by dust in the same volume of space as the cluster.

Note on the Nebulosity Around RS Puppis. BENGT WESTERLUND, *Uppsala Southern Station, Mount Stromlo Observatory, Canberra, Australia.*—During a survey of the southern Milky Way with the 20/26-inch Schmidt telescope at Uppsala Southern Station a weak nebulosity has been found around the Cepheid RS Puppis. It appears likely that we have here a diffuse nebula reflecting the light from RS Puppis. To our knowledge no Cepheid is previously known to be so directly associated with interstellar matter. The maximum extension of the nebula from the star is approximately 1.4 minutes of arc. This appears sufficiently large to permit detection due to the pulsation of the star. The region is being photographed regularly with the 74-inch telescope at Mount Stromlo Observatory.

Population I in the Large Magellanic Cloud. BENGT WESTERLUND, *Uppsala Southern Station, Mt. Stromlo Observatory, Canberra, A.C.T. Australia.*—Blue, visual, red, and infrared magnitudes have been measured for a total of about 1450 stars in five regions near 30 Doradus and Constellation III. The limiting magnitude is about $V=16$ mag. Color-magnitude diagrams are presented for 26 associations,

clusters, and fields. The following are identified by NGC numbers: 1962-5-6-70, 1983, 1984, 1994, 2004, 2011, 2014, 2021, 2074, 2081, 2092, and 2100.

The color-magnitude arrays consist generally of a fairly unbroken vertical main sequence above which a few very luminous stars may be scattered, and, in most cases, of a group of red supergiants. Several of the very luminous blue stars are of type Be or Of. It may be noted that all the identified Wolf-Rayet stars are found at the upper end of the unbroken main sequence. This point has been tentatively identified as the turnoff point.

The interstellar reddening is moderate; the total absorption is generally below $A_V=1$ mag. If the fast evolution of these very young (ages between 3 and 10×10^6 years) and very massive stars is taken into consideration a good agreement is obtained between the observed distribution of stars and the initial luminosity function. The total masses of the clusters and associations appear to be of the same order of magnitude as those of the corresponding galactic objects.

The photometry is based on van Wijk's sequence as revised by P. F. and B. J. Bok and on a sequence established by Eggen and Sandage in Constellation III. Additional photoelectric observations have been carried out with the 30-inch reflector at Mt. Stromlo Observatory. The photographic material consists of plates taken with the 20/26-inch Schmidt telescope at Uppsala Southern Station and with the 74-inch telescope at Mt. Stromlo Observatory.

Astronomical Tests of an Imaging Photomultiplier. W. L. WILCOCK, *Imperial College, London, England*, AND W. A. BAUM, *Mount Wilson and Palomar Observatories, California*.—An imaging photomultiplier tube described by Wilcock, Emberson, and Weekley (*IRE Trans. NS-7*, 126-132, 1960) was used experimentally for astronomical observations at the Lowell Observatory in April, 1960. The tube has an antimony-cesium photocathode, five electron-multiplying dynodes, and a blue phosphor screen. The dynodes are extremely thin membranes of the type described by Sternglass (*Rev. Sci. Instr.* 26, 1202, 1955). Primary electrons incident upon one face of a dynode membrane cause the emission of secondary electrons from the other face. A magnetic field serves to refocus the image from each dynode to the next.

The tube, mounted in a solenoid 19 inches long and 7 inches in diameter, was attached to the $f/16$ Cassegrainian focus of the 24-inch Morgan reflector, where the image scale was 21" per mm. Two 50-mm $f/2$ lenses front-to-front served to transfer the output images from the phosphor screen to photographic plates. The resolution was about 12 line pairs per mm over a total field of 1 cm.

Exposure times required to reach various threshold magnitudes in a field of faint stars in M3 were compared with the exposure for unaided photography. For short unsaturated exposures during mediocre "seeing" (star diameters $\sim 6''$), the speed gains of the tube at 25 and 30 kv were 10-fold and 90-fold, respectively. At 30 kv the ultimate limit was estimated to be about 1.5 mag. less faint than the theoretical limit for unaided photography. This difference suggests that the average number of blackened grains per photoelectron at 30 kv was about 8, an estimate which is not inconsistent with the degree of lumpiness observed in the 30-kv images.

The Bolometric Solar Constant Related to Radiation Pressure Effects on Satellites. RAYMOND H. WILSON, JR., *NASA Goddard Space Flight Center, Code 501.3, Washington 25, D. C.*—Radiation pressure on the 100-foot balloon satellite Echo I (1960 Iota I) has increased its orbital eccentricity from 0.01 to 0.06 in three months. In any precise discussion of this effect, such as has been given for Vanguard I (Musen, Bryant, and Bailie, *Science* 131, 1935, 1960), the assumed pressure depends directly on the solar constant and related effective temperature. For the latter Wien's law gives 6150°K, implying local $T=419^\circ\text{K}$ at 1 a.u. on a perpendicular black plane (Wilson, *Science* 127, 811, 1958), and for an isothermal sphere the radiation pressure is $aT^4/4=5.83 \times 10^{-5}$ dynes per cm^2 of cross section, where a is the energy density constant. The corresponding bolometric solar constant is 25% higher than the 2.0 cal/ cm^2/min assumed by Musen *et al.* However, since their Vanguard I calculations neglected pressure reduction by 20% shadowing and 2% reflected radiation from the earth, the higher solar constant seems equally compatible with the observations. The corresponding solar bolometric absolute magnitude would be brightened by 0.25 to +4.57. Thus Echo-type satellites having very large cross section-to-mass ratios may serve from studies of their orbital perturbations as precise indicators of fundamental astrophysical constants.

The total pressure found for a black sphere can be shown to hold unchanged by specular reflection, since the integrated reflection from a hemisphere would produce zero resultant force. By similar reasoning the actual satellite temperature governing its reradiative rate will not, since such radiation is isotropic, affect the resultant force, provided the sphere is isothermal. However, nonuniformity of temperature due to spin-axis tilt and slow heat transfer could double the resultant pressure on a hot surface or halve it on a cool surface, the change depending on satellite temperatures. Likewise, it can be shown that for a fraction A of diffuse reflection the pressure would be multiplied by $(1+4A/9)$.

Atmospheric Drag on Artificial Satellites.

PEDRO E. ZADUNAISKY, *Smithsonian Astrophysical Observatory, Cambridge, Massachusetts*.—The rate of decrease of the anomalistic period P of an artificial satellite caused by atmospheric drag can be expressed in the form $dP/dt = -3C_D(S/m)aF(e, \rho)$ where C_D = drag coefficient, S = effective cross section of the satellite's mass of the satellite, a = semimajor axis of satellite's orbit, e = orbital eccentricity and ρ = atmospheric density. The function $F(e, \rho)$ is a certain integral computed along a complete revolution of the satellite on its orbit. To evaluate such an integral it is usually assumed that ρ can be expressed by $\rho = \rho_0 \exp(-Z/H)$ where ρ_0 is the atmospheric density at perigee, Z is the height above perigee and H is the density scale-height. The expression given above can then be used to derive the atmospheric density at perigee, when dP/dt is known, or vice versa, provided that, besides the orbital elements of the satel-

lite, sufficiently accurate values of C_D , S/m , and H are determined or assumed in advance.

According to recent results C_D should depend on the height of the satellite and its shape; if the satellite is nonspherical the value of S depends on the way the satellite tumbles; finally the scale height H experiences variations due to the solar activity through a mechanism which is far from being well known.

In this paper an attempt is made to build up an internally consistent picture of the variation of all these quantities by using orbital data from several satellites simultaneously and covering a period of time of several months. For a correct intercomparison of these data the diurnal effect of solar activity is removed, by assuming a suitable model of the earth's atmosphere.

Some results have been obtained which show a reasonable agreement with experimental evidence drawn from sources not directly related to the drag phenomena.

Tidal Deformations and the Origin of the Moon*

ERNST J. ÖPIK†

Department of Physics, University of Maryland, College Park, Maryland

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Results of a provisional survey of the ellipticities of lunar craters in selected areas of Kuiper's *Atlas* are discussed. The rms random ellipticity is found to be 0.070 near the center, 0.096 near the limb, and is probably due to oblique impact. Small preferential components of ellipticity are indicated and interpreted as possible after-effects of past tidal deformations. Formulae for tidal-rotational deformations of line elements on an elastic nonresisting surface are given. The smallness of the preferential effects is in itself significant, without regard to their absolute value. They suggest that the craters were formed when the earth-moon distance was of the order of 30 000–50 000 km. The undamaged appearance of the craters except for impact erosion and flooding, and the absence of signs of major crustal deformations indicates that since crater formation the moon could not have been at a closer distance. From theoretical rates of accretion as based on probabilities of interplanetary collisions,

possible modes of origin of the moon are discussed. If the pre-mare craters mark the end of a continuous process of accretion which built the moon, the observed small systematic deformations of the craters are only compatible with the moon having accreted from a cloud of fragments circling the earth in direct orbits at a distance of five to eight earth radii or greater. The assumption of different processes for accretion of the moon and for the formation of pre-mare craters leads to improbable consequences. Only when the preferential ellipticities are discounted as due to other causes or to chance, is it possible to accept the alternative of the moon having accreted from interplanetary material orbiting the sun. Accretion must then have run simultaneously with tidal evolution following initial tidal capture, the pre-mare craters having formed at a distance of over 200 000 km from earth as the final stage of this accretion.

I. INTRODUCTION

SYSTEMATIC trends in the ellipticity of lunar craters may offer a valuable additional criterion for the controversial problems of the origin of the moon, as well as its internal and surface structure. According to the theory of tidal evolution, in the immediate past the moon was nearer to earth, when its tidal distortion may have been considerable. Impact craters formed at that time must subsequently have undergone deformation when the moon assumed its present more nearly spherical shape.

Actually, impact craters never are expected to be exactly circular; a slight ellipticity is predicted by the theory of impact, depending upon the angle of incidence and the "explosiveness" of the collision. The deformations superimposed on this random ellipticity will lead to elongation in a certain preferential direction, depending upon the location of the craters in relation to the tidal and rotational axes. If small, this preferential orientation can be revealed only by a statistical approach.

Considering that the observed craters are purely superficial structures whose formation could not have altered appreciably the distribution of mass in the moon, it appears legitimate to assume the present axes and moments of inertia for the epoch of crater formation. In that case the tidal apex is to be identified with its present position near the center of the lunar disk.

The expected preferential ellipticities of the craters consist, thus, of an elongation in the meridional direction near the center, and foreshortening in the radial direction near the limb (see Sec. IV). The areas where

crater shapes were studied have been selected accordingly.

The present study is of a preliminary character, yet the outcome is quite definite, yielding a small effect in the expected direction, equal to $2\frac{1}{2}$ to 4 times its probable error. It can be interpreted as indicating that the craters were formed at a considerable distance from the earth, when tidal deformation of the moon was small. The smallness of the effect is significant in itself, regardless of the uncertainty in its absolute value.

II. CENTRAL AREAS

Ellipticities of craters within 12° from the center of the lunar disk were estimated and measured on selected charts of Kuiper's *Atlas* (1960). Only charts with favorable illumination were chosen; their atlas numbers are C4a, b; C5a, b; D4a; and D5a, c. The diameters refer to the crater rim; the identification of the proper position of the rim requires a study of the shadow effects and involves personal judgment. All craters exceeding 7 mm (1 mm = 1.37 km on the map) were measured whose rim could be reliably identified either continuously, or by interpolation through irregularities.

The position angle α of the major axis of the crater relative to the lunar meridian was estimated, and the axes a and b of the crater were measured with an accuracy of 0.1 mm. The apparent ellipticity of the crater is then

$$\epsilon = (a - b)/a. \quad (1)$$

The share of geometrical projection in determining the apparent ellipticity was small as compared with the natural dispersion in ϵ and can be provisionally neglected.

The averaging of observed ellipticities requires special treatment. When ϵ is small, the central polar

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† On leave from Armagh Observatory, Northern Ireland.

equation of the ellipse can be represented as

$$\Delta r = \frac{1}{2}\epsilon \cos 2\beta, \quad (2)$$

in units of the mean radius $\frac{1}{2}(a+b)$ and neglecting terms of the order of ϵ^2 and higher. Here

$$\Delta r = r - 1,$$

and β is the angle between the radius vector r and the major axis.

Let two observed ellipses with ellipticities ϵ_1 and ϵ_2 , forming an angle A between their major axes, be combined into an average ellipse of ellipticity $\bar{\epsilon}$, forming an angle $\bar{A}$ with the major axis of the first ellipse. According to Eq. (2), the average radius vector in an arbitrary direction β is then

$$\bar{\Delta r} = \frac{1}{4}[\epsilon_1 \cos 2\beta + \epsilon_2 \cos(2\beta - 2A)] = \frac{1}{2}\bar{\epsilon} \cos(2\beta - 2\bar{A}). \quad (3)$$

Differentiation of Eq. (3) by β yields

$$\frac{1}{4}[\epsilon_1 \sin 2\beta + \epsilon_2 \sin(2\beta - 2A)] = \frac{1}{2}\bar{\epsilon} \sin(2\beta - 2\bar{A}), \quad (4)$$

and the sum of the squared Eqs. (3) and (4) leads then to

$$\bar{\epsilon}^2 = (\frac{1}{2}\epsilon_1)^2 + (\frac{1}{2}\epsilon_2)^2 + 2(\frac{1}{2}\epsilon_1) \cdot (\frac{1}{2}\epsilon_2) \cos 2A. \quad (5)$$

Hence $\bar{\epsilon}$ is equal to one-half the vector sum of ϵ_1 and ϵ_2 , applied under an angle $2A$, or the double of the mutual inclination.

Thus generally, ellipticities can be treated as vectors of scalar value ϵ and with the directional angles doubled. The scalar value of the difference between two observations is then

$$\Delta\epsilon = (\epsilon_1^2 + \epsilon_2^2 - 2\epsilon_1\epsilon_2 \cos 2A)^{\frac{1}{2}}. \quad (6)$$

With $\beta_m = \alpha$ denoting the position angle of the major axis relative to the lunar meridian, and $\beta_e = 90 - \alpha$ being the angle between the major axis and the equatorial direction, Eq. (2) defines the bias of ϵ in the meridional direction as

$$\xi = \Delta r_m - \Delta r_e = \epsilon \cos 2\alpha. \quad (7)$$

Altogether, 53 craters in the central region were measured. Care was taken to obtain reliable rim-to-rim diameters, most conveniently measured at oblique illumination as the distance between the crest borderlines of the inner and outer shadows of the wall. Irradiation displaces the two shadow borders in the same direction and is unlikely to produce important systematic errors in the diameter. Usually both diameters, at right angles to one another, could be measured according to this rule. When one of the diameters was more or less parallel to the terminator, so that the shadow borders could not be seen, interpolation from diameters inclined at a small angle to the terminator was applied with proper judgment. Owing to this and to the circumstance that the terminator is approximately parallel to the lunar meridian, some systematic error in the bias ξ could have resulted; the error is difficult to assess but is probably very small.

TABLE I. Distribution of observed ellipticities (ϵ) in central region.

ϵ	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
n	8	5	3	1	5	1	10	2	0
$\bar{\epsilon}$	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.18	All
n	3	3	3	1	1	4	2	1	53

From 37 craters measured on two plates the quadratic mean of the vector difference in ϵ , as defined by Eq. (6), was found to be

$$\Delta\epsilon = 0.0645, \quad (8)$$

whence the scalar probable error in ϵ of a single plate becomes

$$\text{p.e. } (\epsilon) = 0.674 \Delta\epsilon / \sqrt{2} = 0.0308. \quad (9)$$

This "observational" error is chiefly caused by irregularities in the rim and their different interpretation at different illumination.

The observed distribution of the ellipticities, counted to the nearest 0.01, is given in Table I.

Hence the observed mean-square value of ϵ equals

$$\epsilon_q = 0.0798. \quad (10)$$

With a fraction of $k = 37/53$ craters observed twice, and an average component of ellipticity $\epsilon_p = 0.012$ due to projection, the true or *cosmic* dispersion in crater ellipticities, ϵ_c , as defined by

$$\epsilon_c^2 = \epsilon_q^2 - \epsilon_p^2 - (\frac{1}{2} - \frac{1}{4}k)\Delta\epsilon^2, \quad (11)$$

becomes

$$\epsilon_c = 0.0698. \quad (12)$$

The scale errors of the *Atlas* are supposed to be of the order of 1-2% (Kuiper 1960). Moreover, the scale has been found to be anisotropic, varying with direction according to a law similar to Eq. (7) and thus directly affecting the bias. The anisotropy of the chart scales was assessed by comparing them with Chart 1 of the *Atlas*; the lunar diameters of this chart yield an anisotropy of $1 + 0.125 \cos 2(\alpha - 14^\circ)$, where α is the position angle counted west of north; the position of the limb beyond the terminator of the small lunar phase (8.5°) was calculated from the foreshortening of marginal craters. From the ratio of the distances of certain pairs of objects to those on Chart 1, the anisotropy of the central charts was determined. The average absolute correction for anisotropy for the seven central charts was found to be

$$\Delta\xi_{av} = \pm 0.018,$$

thus of the order of the bias itself.

The mean bias as defined by Eq. (7) was found as follows:

Quadrants	C_8	$C_4 + D_4 + D_8$	All
Number of craters	25	28	53
$\bar{\xi}$, uncorrected	+0.0202	+0.0125	+0.0161
$\bar{\xi}$, corrected for anisotropy	+0.0192	+0.0242	+0.0218
p.e.	± 0.0076	± 0.0071	± 0.0052

TABLE II. Correlation of bias and crater diameter for central regions.

Diameter, mm	7-13	13-20	20-30	30-44	>44
η	24	10	7	6	6
ξ	+0.003	+0.025	+0.033	+0.047	+0.002
p.e.	± 0.008	± 0.012	± 0.014	± 0.015	± 0.015

The differences between the solutions are not significant. Conventionally the total uncorrected average can be adopted,

$$\xi = +0.0161 \pm 0.0052 \text{ (p.e.)} \quad (13)$$

The plus sign corresponds to elongation in the expected meridional direction. The mean-square deviation $\xi - \xi$ for the 53 craters was

$$\Delta\xi = \pm 0.0557,$$

which corresponds to a probable deviation for one individual crater of

$$\text{p.e. } (\xi) = \pm 0.0375. \quad (14)$$

This represents the total dispersion from cosmic and observational sources, although the share of purely observational errors is relatively small. The probable error in ξ in Eq. (13) and elsewhere is calculated with this value. Table II shows the dependence of ξ upon diameter. No significant correlation is indicated, and no systematic correction was applied in this respect. As to the systematic influence of geometrical projection, $(\cos 2\alpha)_{av} \approx 0$ as for symmetric distribution around the center of the disk, and Eq. (7) suggests that the influence is negligible.

III. CRATER ELLIPTICITIES IN LIMB AREAS

Apparent ellipticities were measured in selected limb areas of Kuiper's *Atlas* (1960) as listed in Table IV. Systematic errors are even more likely to affect these measures than the central areas.

Because of perspective, the intrinsic ellipticities and orientations of craters in the limb areas cannot be directly seen or simply determined. Only a comparison of radial to transversal dimensions was therefore made.

Altogether 125 craters were measured within a distance of from 4 to 30 cm from the limb, or within an angular distance θ of from 75° to 50° from the center of the disk; the average angular distance was around $\theta = 66^\circ$. The angle θ was calculated from

$$\sin \theta = 1 - h/R, \quad (15)$$

with $R = 125$ cm assumed constant for all charts. Variations in the scale of the individual photographs have relatively small effect on the calculated value of θ , as follows from the differentiation of Eq. (15) (for $h = \text{const}$):

$$d(\cos \theta) = -\tan \theta (1 - \sin \theta) dR/R. \quad (16)$$

With b and a denoting the apparent diameters in the radial (foreshortened) and transversal (unforeshortened) directions, the transversal bias, η , positive for an excess in a or a deficiency in b , is defined by

$$\eta = 1 - (b \sec \epsilon)/a. \quad (17)$$

From 24 craters measured on two plates the observational error in η for one plate was found to be

$$\text{p.e. } (\eta) = \pm 0.0277 \text{ (observational)}, \quad (18)$$

practically equal to that of Eq. (9).

The deviations from the separate averages of each region yield for the total individual probable deviation in η for one crater a value of

$$\text{p.e. } (\eta) = \pm 0.0533, \quad (19)$$

which is higher than that for ξ [Eq. (14)], implying a lower statistical weight for the limb observations.

Subtracting the observational dispersion from the total, the cosmic rms dispersion in the component η of the ellipticity is found to be

$$\eta_o = \pm 0.0677, \quad (20)$$

whence the rms ellipticity follows as

$$\epsilon_o' = \eta_o \sqrt{2} = 0.0957. \quad (21)$$

This is considerably larger but of lower weight than the value of Eq. (12) for the central regions.

Imperfect photographic definition may have increased b and a by equal amounts, systematically affecting η in Eq. (17), toward negative values. If Δ is the definition of the plate, we may set

$$a = a' - k\Delta, \quad b = b' - k\Delta, \quad (22)$$

where a' and b' are the observed diameters. By differentiation of Eq. (17), the correction of η is then a linear function of the reciprocal diameter,

$$\Delta\eta = \eta - \eta' = +k\Delta(\sec \theta - 1)/a. \quad (23)$$

The definition of the charts was estimated as follows:

Chart	A2a	A2d	A4a	A4b	B8a	C1a	D1a	D8a
Δ , mm	0.6	0.4	0.5	0.7	0.4	0.8	0.5	0.5

The effect of the corrections, applied according to Eq. (22) with different values of the proportionality factor k , is shown in Table III; n' is the number of measurements, not craters.

According to Eq. (23) the expected correlation is of the form

$$\bar{\eta} = C/a + \text{const.}$$

For $k=0$, $C = -0.37$ is found, and for $k=1$, $C = +0.26$. At $k=0.6$, $C=0$; this value of k was finally adopted. There is still considerable uncertainty in this correction, as well as in the ensuing value of the limb bias effect, except that $\bar{\eta}$ is small and positive.

Table IV contains the results for the individual limb regions.

TABLE III. Correlation of η with the reciprocal diameter for limb regions.

a , mm	7-13	13-20	20-30	30-44	>44	All
Av. $1/a$	0.091	0.060	0.040	0.027	0.014	...
$(k=0)\bar{\eta}$	-0.021	-0.021	+0.001	-0.007	-0.006	-0.011
$(k=1)\bar{\eta}$	+0.031	+0.019	+0.027	+0.012	+0.007	+0.020
$(k=0.6)\bar{\eta}$	+0.010	+0.003	+0.017	+0.004	+0.002	+0.008
n'	37	26	27	30	30	150
p.e. in $\bar{\eta}$	± 0.009	± 0.010	± 0.010	± 0.009	± 0.009	± 0.004

No corrections for scale were made. The scale errors are more or less accidental, as found for the central regions, and would thus add to the random statistical error of the small samples.

IV. TIDAL AND ROTATIONAL DISTORTION

Formulae for small tidal and rotational distortions of spherical bodies have been given by Tisserand (1891), Jeffreys (1929 and 1952), and others. Here we are mainly concerned with the *strains* in the outer skin or crust, induced by body deformations.

When the perturbing body (earth) is approximated to a point mass, the deformations can be derived in an elementary manner for all the mass in the center, or an infinite concentration of mass in the perturbed body (moon), to be called the "standard case." For an arbitrary spherically symmetrical distribution of density in the perturbed body, the deformations are obtained by multiplying those of the standard case by a factor K depending on the density distribution, and equal to the ratio of double oblateness or prolateness to the maximum relative perturbation of surface gravity. For a constant density in the perturbed body, $K=2.5$; for the earth, $K=1.85$. The moon is undoubtedly less centrally condensed than the earth and $K=2.5$ can be set as a very close approximation.

Let (M, R) and (m, r) be the mass and radius of earth and moon, respectively, D their distance, ω_0 the angular velocity of orbital motion, ω that of axial rotation of the moon, and let

$$f = Mr^3/mD^3 \quad (24)$$

be the tidal perturbation parameter; also,

$$\omega_0^2 = G(M+m)/D^3 \approx GM/D^3, \quad (25)$$

with G the gravitational constant.

Small tidal perturbation vectors are equivalent to

rotational vectors of complex angular velocity ω_i , such that

$$\omega_i^2 = -3\omega_0^2, \quad (26)$$

and with a decreased total mass m' ,

$$m' = (1-2f)m.$$

Thus, when f is small, both kinds of perturbations can be treated by analogous formulae. In the general case of nonsynchronous rotation, with

$$\omega^2 = \gamma\omega_0^2, \quad (27)$$

and for constant volume and surface area (to terms of first order of f) the equilibrium equation of the distorted surface becomes

$$\Delta r = Kf r (1 - \frac{3}{2} \sin^2 \theta - \frac{1}{2} \gamma + \frac{1}{2} \gamma \cos^2 B), \quad (28)$$

with θ =angular distance from the tidal apex, B =the latitude or angular distance from the equator of rotation, and Δr =excess of radius over its average or spherical value r .

For synchronous rotation, $\gamma=1$, when the tidal apex is on the equator of rotation and for $K=2.5$ as for uniform density, the well-known values (Tisserand 1891) for the three principal axes result:

$$\text{Pole of rotation, } \theta=90^\circ, B=90^\circ, \Delta r/r = -25f/12;$$

$$\text{Intersection of tidal and rotational equator, } \theta=90^\circ, B=0^\circ, \Delta r/r = -10f/12;$$

$$\text{Tidal apex, } \theta=0^\circ, B=0^\circ, \Delta r/r = +35f/12.$$

Assuming the surface to yield freely to the perturbation and each point to be displaced in proportion to, and in the direction of, the perturbation vector, without, however, losing contact with the neighboring points (a kind of elastic skin with negligible resistance), the relative distortions $\delta = \Delta l/l$ of a line element l on the surface are given by the following formulae:

TABLE IV. Limb bias effect, η . $(\cos \theta)_{av} = 0.40$; B =average selenographic latitude; χ =angle between tidal and rotational meridians; n =number of individual craters.

Charts	A2a, d	A4a, b	B8a	C1a	D1a	D8a
B	+38°	+9°	-56°	+64°	+64°	-64°
χ	70°	86°	50°	27°	27°	27°
n	25	7	24	18	18	33
$\bar{\eta}$, uncorr.	-0.0149	-0.0219	-0.0159	-0.0150	-0.0353	+0.0159
$\bar{\eta}$, corr. ($k=0.6$)	+0.0019	-0.0094	-0.0022	+0.0129	-0.0123	+0.0345
p.e. ($\bar{\eta}$)	± 0.0106	± 0.0200	± 0.0108	± 0.0125	± 0.0125	± 0.0092

Tidal strain in tidal meridians,

$$\delta_{tm} = \frac{1}{2}Kf(3 \sin^2\theta - 1), \quad (29)$$

and in tidal parallels,

$$\delta_{tp} = -\frac{1}{2}Kf; \quad (30)$$

rotational strain in rotational meridians,

$$\delta_{rm} = \frac{1}{6}\gamma Kf(1 - 3 \cos^2 B), \quad (31)$$

and in rotational parallels,

$$\delta_{rp} = +\frac{1}{6}\gamma Kf. \quad (32)$$

The total strain of superimposed tidal and rotational distortions is then

$$\delta_m = \delta_{tm} + \delta_{rm} \cos^2 \chi + \delta_{rp} \sin^2 \chi \quad (33)$$

along tidal meridians, and

$$\delta_p = \delta_{tp} + \delta_{rm} \sin^2 \chi + \delta_{rp} \cos^2 \chi \quad (34)$$

along tidal parallel (at right angles to the meridians).

Similarly, the total superimposed strains on the rotational system become

$$\delta'_m = \delta_{tm} \cos^2 \chi + \delta_{tp} \sin^2 \chi + \delta_{rm}, \quad (35)$$

$$\delta'_p = \delta_{tm} \sin^2 \chi + \delta_{tp} \cos^2 \chi + \delta_{rp}. \quad (36)$$

Here χ is the angle between the tidal and rotational meridians. The formulae are valid for arbitrary rotation. For synchronous rotation and uniform density, $\gamma = 1$ and $K = 2.5$, the characteristic distortions become:

$$\text{At pole of rotation, } \delta_m = +35f/12, \quad \delta_p = -10f/12;$$

At the equatorial limb,

$$\delta_m = +35f/12, \quad \delta_p = -25f/12;$$

$$\text{At the tidal apex, } \delta'_m = -25f/12, \quad \delta'_p = -10f/12.$$

In nonsynchronous rotation, for a given point the angle θ is variable; in the statistics of crater deformations the average value of δ_{tm} for one rotation should then be taken, which requires an additional factor of $\frac{1}{2} \cos^2 B$ in the first term in parentheses of Eq. (29). This would reduce the effect to practically zero in the polar region, contrary to the evidence of Table IV, where a positive effect is more or less indicated.

It is also improbable that the moon's rotation was not synchronized with its orbital revolution at any phase of its tidal evolution. If $\omega'_0 = -d\omega_0/\omega_0$ is the relative rate of change of the orbital period of revolution, and $\omega' = -d\omega/\omega$ the corresponding rate for the period of axial rotation of the moon, it can be shown that

$$\omega'/\omega'_0 = 2.5\mu\gamma^{-\frac{1}{2}}(D/r)(M/m)^{2.5}(r/R)^7, \quad (37)$$

positive when $\omega > \omega_0$. Here μ is a relative friction coefficient of the order of unity, depending on the lag angle of the tidal bulge, the elasticity and the rigidity. For $\mu = 1$, $\gamma = 6.25$ or 2.5 rotations per one orbital revolution, Eq. (37) becomes

$$\omega'/\omega'_0 = 6D/r. \quad (37')$$

Even for the closest distance compatible with tidal evolution (Gerstenkorn 1955), $D/r = 10.6$, $\omega'/\omega'_0 = 64$. Thus the adjustment of the moon's rotation to orbital revolution must have been extremely rapid, and, for the epoch of formation of the craters, it is legitimate to consider the only case of $\gamma = 1$, with the present relative orientation of the tidal and rotational axes.

Let a crater near the center of the lunar disk have been impressed as a circle on a field whose distortion bias in the meridian direction was equal to $\delta'_m - \delta'_p$; with the return of the moon to spherical shape, the crater must have become distorted, with an apparent bias equal to $-(\delta'_m - \delta'_p)$. For the central regions, with $(\sin^2\theta)_{av} = 0.027$, $(\cos^2 B)_{av} = 0.98$, $\gamma = 1$, Eqs. (29) and (30), substituted into Eqs. (35) and (36) with $(\cos^2 \chi)_{av} = \frac{1}{2}$, yield for the present bias in meridional direction

$$\xi = \delta'_p - \delta'_m = +0.49Kf. \quad (38)$$

Similarly, for the craters in limb areas the present transversal bias becomes

$$\eta = \delta'_m - \delta'_p,$$

or, according to Eqs. (29)–(34),

$$\eta = \frac{1}{2}Kf(3 \sin^2\theta - \cos^2\beta \cos 2\chi). \quad (39)$$

Substituting the values of η , θ , B , and χ of Table IV into Eq. (39), and ξ of Eq. (13) into (38), a system of seven equations for the determination of Kf is obtained. Assigning to Eq. (13) a weight of $2n = 106$, and weights equal to n to the remainder, a least-squares solution is obtained from all areas and a total of 178 craters,

$$Kf = +0.0087 \pm 0.0034 (\text{p.e.}), \quad (40)$$

the scale errors of the single charts being disregarded and treated as accidental. The mean-square ratio of deviation to probable error for the seven equations is 1.64, 10% greater than the theoretical random value of 1.49, which is satisfactory.

With $K = 2.5$ as for uniform density, $f = 0.0035 \pm 0.0014$ results. Despite the large probable error, the outcome is definite in showing that the tidal distortion of the moon was small at the time of crater formation. From Eq. (24), with $M/m = 81.5$, $r = 1738$ km, this value of f yields $D/r = 29.7$ and

$$D = 8.1R = 50\,000 \pm 7000 \text{ km.} \quad (41)$$

The neglect of the scale distortions is one weakness of the solution as represented by Eqs. (40) and (41); another consists in its dependence on the correction for photographic definition which involves a greater uncertainty than implied by the statistical error.

Using the result as corrected for scale errors for the central regions only, Eq. (38) becomes

$$0.49Kf = +0.0218 \pm 0.0052, \quad (42)$$

whence, with $K = 2.5$,

$$f = +0.0179 \pm 0.0042,$$

and

$$D = 4.5R = 29\,000 \pm 2300 \text{ km.} \quad (43)$$

The result is apparently more significant than that of Eq. (41) but, being based on 53 craters and one region only, with a distortion ascribed solely to rotation without the tidal component (which is symmetric around the tidal apex), its significance must not be exaggerated. Conventionally, for the purposes of further discussion, a middle value between the two is assumed, $D = 37\,000 \text{ km} = 5.8 R$.

V. THE ORIGIN OF THE MOON

Cosmogonic theory can never arrive at unique solutions of its problems. The possible presence of bodies and environment in the remote past which have since then disappeared opens the door to a variety of *ad hoc* hypotheses, making extrapolation beyond a certain epoch in the past illusory. What we can hope for is to choose the more *probable*, possibly the more simple hypothesis, and arrive thus at a *probable* model of formation of the celestial bodies. Even if acceptable statistically, there is no guaranty that the method may not fail in individual cases. The same holds with respect to the tidal history of the moon, and the following deliberations must be viewed with this reservation in mind.

The density of small craters in the lunar *maria* corresponds closely to the expected number of collisions with asteroidal and cometary objects during the entire lifetime of the solar system (Öpik 1960), whereas the density of large craters is greater. These and especially the craters in the lunar *continentes* are too numerous to be accounted for by a currently continuing process and must be ascribed to an extremely intense bombardment of short duration at the dawn of the solar system. Most probably but not necessarily they represent the closing stage of the building up of the moon.

If the moon was accreted from debris ranging in size from asteroids to dust, craters and *maria* must have formed continuously during the process, to be buried and obliterated under layers of subsequent accretion.

The last stage of accretion which gave the lunar surface its present appearance could have added only a small fraction to the lunar mass. The volume eroded by the final stage of bombardment corresponds to a layer of the order of the average depth of a crater in the *continentes*, or about 0.5 km. The accreted volume must be much smaller; at a velocity of impact of 3–5 km/sec, it is of the order of 2–1% of that of erosion (Öpik 1960), equivalent to a layer of about 50 m, or a fraction of $\Delta = 3 \times 10^{-6}$ of the radius of the moon.

Let us now assume that the continental craters of the moon indeed represent the final stage of one continuous process of accretion which built the moon from one cosmic source; this is the simplest and, therefore *a priori*, the most probable and plausible assumption.

TABLE V. Collision lifetimes τ and velocities of encounter U .

Average orbital eccentricity and inclination, $e = \sin i$	0.05	0.10	0.20
(1) Sunbound particles swept by the earth			
U , km/sec	2.1	4.2	8.3
τ , 10^6 years	2.8	16.5	90.
(2) Earthbound particles swept by the moon at $D = 37\,000 \text{ km}$			
U , km/sec	0.23	0.45	0.90
τ , years	0.64	4.0	27.

In such a case, with accretion removing the debris from the surrounding space and thus depleting the source, the process at the end asymptotically approaches that of exponential decay on a time scale τ , so that the density of debris in the source varies then as $\exp(-t/\tau)$ (Öpik 1951). For a certain model of depletion where a finite store of material is given in the beginning and the variable collision cross section is allowed for, the time of accretion is found to be close to

$$t_0 = 12\tau - 1.05\tau \ln(20\Delta), \quad (44)$$

or, with the value of Δ as estimated,

$$t_0 \approx 20\tau. \quad (45)$$

The result is insensitive to the actual value of Δ , as well as to the model chosen. The first term of Eq. (44) gives the time of accretion to 0.95 of the radius, the second from 0.95 to $1 - \Delta$.

Accretion by the moon can be effective only at low velocities of impact, of the order of 5 km/sec or less (Öpik 1960). At high velocities more material is lost to space than is accreted. Hence cometary and Apollo-type asteroidal objects are excluded, and two sources of accretion are only to be considered: (1) Sunbound objects with more or less asteroidal orbits of small eccentricities and inclinations in the vicinity of the earth's orbit; (2) earthbound fragments in a cloud or ring surrounding the geocentric orbit of the growing moon.

The time rates of depletion or "sweeping out" of the sources can be calculated from the geometrical theory of probabilities of planetary collisions (Öpik 1951) and are collected in Table V. The lifetimes, corresponding to a depletion factor if e^{-1} , refer to physical collisions only. Repeated perturbations in close approaches cannot remove the objects from the sphere of action of the sweeping body at the small relative velocities of encounter here considered; therefore collision lifetimes in this case are identical with total lifetimes. The velocities of encounter are those undisturbed by the gravitational field of the sweeping body, and their directions are isotropic, with respect to the moving earth in the first case, relative to the moon in the second. Therefore, in the second case there will be no east-west asymmetry in the frequency of impacts and of craters, despite the moon's eastern hemisphere preceding in its orbital motion.

For the asteroids between Mars and Jupiter the median orbital elements are $e = \sin i = 0.15$. For the primordial ring of debris from which the earth or the moon have accreted, somewhat smaller values appear to be appropriate, and we may set $e = \sin i = 0.1$, using thus the data in the middle column of the table.

Thus, for the first type of objects the collisional lifetime τ with respect to the earth is of the order of 16 million years; according to Eq. (45) the time of formation of the earth, and of the moon as a by-product in these asteroidal collisions, is then about 300 million years.

In the second case, when the distance of 37 000 km from earth is conventionally assumed, the sweeping rate by the moon corresponds to $\tau \approx 4$ years and the time of building-up of the moon from earthbound material becomes $t_0 \approx 80$ years.

Let us consider the second case in more detail. According to Gerstenkorn (1955) (cf. also Öpik 1955), whose work closely follows Sir George Darwin's methods, the tidal evolution of the moon at 37 000 km from the earth was proceeding at such a rate that in 80 years its distance increased only by some 2000 km. Thus the whole process of formation of the moon could have taken place, indeed, within the bounds of a limited ring of diffuse matter and debris circling the earth at the aforesaid distance. The tidal evolution of the moon would then have started at this distance. The hypothesis is internally consistent and, in the writer's opinion, points to the most probable process of formation of the moon.

Returning to the first possibility, namely that of accretion from sunbound orbits, the time of origin of the moon is set back 300 million years, well beyond the hypothetical date of tidal capture which, according to Gerstenkorn (1955), may have taken place 170 million years before the date of closest approach. The time of formation of the present continental craters would then have stretched over some 16 million years, with the moon's perigee distance decreasing from about 20 earth radii (and at highly inclined retrograde motion) to a closest distance of $2.89 R$ (and direct motion), to recede in some 300 years to our hypothetical distance of $5.8 R$. Most of the time being spent, and the majority of the craters being formed, before closest passage, it is unlikely that any surface details would have been preserved after the passage. At $D = 2.89 R$, $f = 0.09$, the linear formulae (29)–(36) yield a maximum elongation of 26% near the limb, and a maximum compression of the surface layer of 19% near the center of the disk, and the true distortion must be even greater. A brittle surface, or one consisting of rubble, would not have preserved almost intact and circular in shape the craters which show only signs of erosion by impact (and flooding in the *maria*), and not by skin distortion. The few clefts or rills on the lunar surface are present exclusively in connection with the *maria* (Baldwin 1949) and must have appeared *after* the continental craters were formed.

It is clear that the moon could not have undergone large tidal deformations after the formation of the craters, and that therefore the hypothesis of accretion of sunbound material over an appropriate long interval of time, of the order of 3×10^8 years, is not supported by this kind of evidence.

It may be noted that the strain tolerance of rocks is very low; for the surface rocks of the earth the tensile strength is only 10^7 dyne/cm², increasing to some 10^9 at a depth of 10–20 km (Gutenberg 1959); the strain tolerance is a fraction of 10^{-5} to 10^{-3} only, and even with the weak strains indicated by the deformation of craters the crust of the moon must have become completely cracked to a depth at which plasticity is conditioned by pressure. In view of the insulating properties of the overlying rubble, the temperature of the coherent crust under the rubble may be rather high, and it may possess plastic properties already at a small depth of a few kilometers, despite the low surface gravity. The cracks in the upper portion of this crust must be hidden under the more recent layer of rubble covering the *continents*. Simple experiments, made by stretching an elastic sheet covered with a layer of sand on which artificial craters are produced by impact of stones, support the arguments of this paper relating to surface deformations.

The question may arise as to what extent the strength of the moon's crust may prevent the calculated deformations and strains from being realized. Disregarding mountains, over extended areas the limb of the moon deviates from an ideal circle by very small amounts, of the order of ± 0.4 km (Hayn 1914; Brouwer as cited by Urey 1951, p. 256). The moments of inertia of the moon derived from physical libration indicate the existence of uncompensated differences in level of the same order of magnitude relative to the mean radius, with density inhomogeneities furnishing an alternative interpretation (Urey, Elsasser, and Rochester 1959). Unpublished analysis by the writer shows that, contrary to widespread opinion, large-scale inequalities in level over the moon's disk are not essentially greater than those observed on the limb. The conclusion is that the moon's crust is unable to sustain large-scale differences in level of more than 1 km or 6×10^{-4} , a fraction of the lunar radius, and that deformations of the order of 0.01 and greater must build up practically to their full equilibrium value.

Therefore, on the hypothesis of *one continuous process of accretion*, from the evidence of the small, yet apparently not negligible, deformations experienced by the lunar craters, and in the light of the theory of tidal evolution, the only mode of formation of the moon consistent with the assumptions and the observational data is its buildup in a direct orbit at a considerable distance from the earth, of the order of 6 earth radii, from earthbound material previously found at that distance.

An apparent alternative would consist in the *ad hoc*

assumption of the process of building up of the main lunar mass having been distinct from that which produced its present surface features. Three successive sources of accretion should then be required: (1) sunbound material which produced the main body of the moon; (2) an earthbound ring of small mass which produced the continental craters; (3) the asteroidal-cometary background of interplanetary space which produced the craters in the *maria*. From the first source, the moon would have accreted as an independent planet in the vicinity of the earth's orbit, during an interval of several hundred million years, the earth having accreted from the same source during the same interval of time as determined primarily by the sweeping action of the earth. After an indefinite period of independent existence, of the order of 10^7 – 10^8 years at least, the moon would have become captured by tidal action into a retrograde orbit, of a perigee distance of $26 R$ (Gerstenkorn 1955). Subsequently, the orbit would shrink at first, then expand, so that the first contact with the earthbound ring would have taken place some 1200 years before closest approach, at a highly inclined retrograde orbit of small eccentricity.

With $i=90^\circ$, $e=0.10$, the collision lifetime at $5.8 R$ for the ring particles with respect to the moon is found to be $\tau=88$ years; during an interval of 1200 years the ring will be completely swept out, and nothing would remain for producing the continental craters *after* closest approach. The same is true in the case where the ring has compacted into a satellite of the earth (which is the most likely course of events); the survival probability of this satellite during the first approach of the moon is negligible. Yet, even assuming that the satellite survived the closest approach, the fragments from its subsequent collision with the moon could not

have escaped and would immediately have fallen back because of the low velocity of encounter. The observed uniform coverage of the *continentes* with craters could not have been achieved in such a case. The proposed alternative is therefore extremely improbable.

If we disregard the evidence of deformation of the craters, as presented here, attributing it to other causes or to errors of observation, one could set the time of crater formation at $\tau=16 \times 10^6$ or more years after the time of closest approach, at a distance of 30 or more earth radii; the moon could then have accreted from interplanetary sunbound matter simultaneously with its tidal evolution. The time scales of the two processes being of the same order of magnitude, this third possibility has against it the observational evidence of deformation which, however, is in need of further study and confirmation.

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The Shape of a Rotating Star Cluster

IVAN KING

University of Illinois Observatory

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A formula is derived for the ellipticity of a rotating star cluster in terms of a mean angular velocity and a mean density. It is identical with Clairaut's formula for a rigidly rotating body of uniform density. The observed ellipticities of globular clusters indicate that in some cases the rotational velocities are as large as the rms random velocities. Rotation causes a slight increase in the rate at which a cluster ejects stars.

IT is intuitively clear that a rotating star cluster should be flattened in much the same way that a rotating solid body becomes oblate. A star cluster, however, is not a solid body and does not rotate rigidly. It is a collection of stars, each moving in its individual orbit in the total gravitational field of the others. Nevertheless, if the total angular momentum is not zero, an average rotational velocity can be ascribed to the system; some relation should exist between this rotational velocity and the over-all shape of the system.

Such a relation can be found by considering partial virial equations, as van Wijk (1949) has done for a tidally influenced cluster. The equations of motion of a star can be written in cylindrical polar coordinates as

$$m_i \left[\frac{d^2 r_i}{dt^2} - r_i \left(\frac{d\theta_i}{dt} \right)^2 \right] = - \frac{\partial U}{\partial r_i}, \quad (1)$$

$$m_i \left[\frac{d}{dt} \left(r_i^2 \frac{d\theta_i}{dt} \right) \right] = 0, \quad (2)$$

$$m_i \frac{d^2 z_i}{dt^2} = - \frac{\partial U}{\partial z_i}, \quad (3)$$

where U is the gravitational potential energy of the system. The axis of rotation is taken to be the z axis, hence the vanishing of $\partial U / \partial \theta_i$. From Eqs. (1) and (3) it follows that

$$\frac{1}{2} m_i \frac{d^2}{dt^2} (r_i^2) = m_i \left[\left(\frac{dr_i}{dt} \right)^2 + r_i^2 \left(\frac{d\theta_i}{dt} \right)^2 \right] - r_i \frac{\partial U}{\partial r_i}, \quad (4)$$

$$\frac{1}{2} m_i \frac{d^2}{dt^2} (z_i^2) = m_i \left(\frac{dz_i}{dt} \right)^2 - z_i \frac{\partial U}{\partial z_i}. \quad (5)$$

If each of these equations is summed over all the stars, the left-hand sides will vanish for a cluster in a steady state. The resulting equations are

$$0 = 2T_r + 2T_\theta - \sum_i r_i \frac{\partial U}{\partial r_i}, \quad (6)$$

$$0 = 2T_z - \sum_i z_i \frac{\partial U}{\partial z_i}, \quad (7)$$

where T_r , T_θ , and T_z are the contributions to the total kinetic energy from the three velocity components.

If Eqs. (6) and (7) are added and Euler's theorem on homogeneous functions is applied to the summation terms, the usual virial theorem results. If, on the other hand, twice Eq. (7) is subtracted from Eq. (6), the result is

$$0 = 2T_r + 2T_\theta - 4T_z - \sum_i \left(r_i \frac{\partial U}{\partial r_i} - 2z_i \frac{\partial U}{\partial z_i} \right). \quad (8)$$

Now T_θ can be considered to consist of two parts: the kinetic energy due to a systematic rotation of the cluster plus the kinetic energy of random motions in the θ direction. Since for most star clusters the time of relaxation is shorter than the age of the cluster, the residual kinetic energies in the three component directions may be expected to be nearly equal. In that case the first three terms in Eq. (8) give

$$\begin{aligned} 2T_r + 2T_\theta - 4T_z &= 2T_{\text{rot}} \\ &= \sum_i m_i r_i^2 \omega_i^2 \\ &= I\omega^2, \end{aligned} \quad (9)$$

where ω_i is the mean angular velocity of stars at a distance r_i from the center, $I = \sum m_i r_i^2$ is the moment of inertia of the cluster about the z axis, and ω^2 is an effective value.

The gravitational terms in Eq. (8) can be simplified if, according to the usual practice, we replace the total gravitational force of the other stars by a smoothed-out potential $V(r, z)$. If the summation is also replaced by an integration with respect to a smoothed-out mass density $\rho(r, z)$, then Eq. (8) becomes

$$I\omega^2 = \int \rho r \frac{\partial V}{\partial r} d\tau - 2 \int \rho z \frac{\partial V}{\partial z} d\tau, \quad (10)$$

where the integrations are to be performed over the whole volume of the cluster.

To proceed any farther it is necessary to assume a density distribution for the cluster. The simplest possible model is a homogeneous oblate spheroid, with constant density ρ , semimajor axis a , and semiminor axis c . For this model

$$I = \frac{2}{5} M a^2, \quad (11)$$

where M is the total mass, while (Ramsey 1940, p. 168)

$$\partial V / \partial r = AG\rho r, \quad (12)$$

$$\partial V / \partial z = CG\rho z, \quad (13)$$

where A and C are constants that depend on the oblateness and G is the constant of gravitation. When the oblateness is small, A and C can be approximated by (Ramsey 1940, p. 170)

$$A = (4\pi/3)(1 - 2\epsilon/5), \quad (14)$$

$$C = (4\pi/3)(1 + 4\epsilon/5), \quad (15)$$

where

$$\epsilon = (a - c)/a \quad (16)$$

is the ellipticity. With these approximations, Eq. (10) gives

$$a^2\omega^2 = (4\pi G\rho/3)[a^2(1 - 2\epsilon/5) - c^2(1 + 4\epsilon/5)]. \quad (17)$$

Finally,

$$\begin{aligned} c^2 &= a^2(1 - \epsilon)^2, \\ &\doteq a^2(1 - 2\epsilon), \end{aligned} \quad (18)$$

and Eq. (17) reduces to

$$\omega^2/\pi G\rho = (16/15)\epsilon. \quad (19)$$

This is identical with the formula for the ellipticity of a fluid body of density ρ , in rigid rotation (Ramsey 1940, p. 177).

Van Wijk has shown (1949) that the shape calculated for a homogeneous spheroidal cluster is valid also for a cluster of moderate central concentration, provided ρ is replaced by a suitable effective value of the density. This approximation is adequate for problems of tidally distorted galactic clusters, to which van Wijk's paper confined itself. But it is in globular clusters that rotational distortions arise, and there the central concentration is often quite high. Thus the approximation of homogeneity is not likely to serve well in the rotational problem. However, it is difficult to improve upon it, since the degree of anisotropy of the velocity distribution and the form of the rotation law $\omega(r)$ are both unknown.

The importance of rotation in the internal dynamics of a cluster may be assessed by comparing the rotational kinetic energy with the random internal kinetic energy. According to the virial theorem, the total internal kinetic energy, including both rotational and random motions, is given by (Chandrasekhar 1942)

$$T = \frac{1}{2}M\bar{v}^2 = \frac{1}{2}GM^2/R. \quad (20)$$

The rotational kinetic energy can be written

$$T_{\text{rot}} = \frac{1}{2}I\omega^2 = \frac{1}{2}MR^2\omega^2. \quad (21)$$

Equations (20) and (21) contain two different effective values of the radius R . If we assume them to be the same, then

$$T_{\text{rot}}/T = 2\omega^2 R^3/GM. \quad (22)$$

But

$$R^3/M = 3/4\pi\rho. \quad (23)$$

If the effective ρ here is the same as that in Eq. (19), then

$$T_{\text{rot}}/T = (8/5)\epsilon. \quad (24)$$

The ellipticities observed in the over-exposed images of globular clusters are certainly caused by rotation rather than by tidal forces. The force of the Milky Way varies linearly across a cluster, while the gravitational attraction of the cluster for its outlying members goes inversely as the square of the distance from the center. The relative importance of the tidal force therefore varies as the cube of the distance from the center. Since the limiting equipotential, beyond which stars are lost outright, is only moderately distorted, the inner equipotentials must be extremely round. Measurements of the shape of integrated cluster images refer to the inner parts, and the observed distortion thus cannot be tidal. Tidal distortions can be detected only in studies of the extreme outer fringe of a cluster, such as Lindsay's (1956) star counts in ω Centauri.

For a number of globular clusters Shapley (1930) gives ellipticities of one or two tenths. For these clusters, Eq. (24) indicates that up to a third of the internal kinetic energy is rotational. In such a case, the rotational velocity is $1/2^{1/2}$ times the rms random velocity, or $(\frac{3}{2})^{1/2}$ times the rms radial component of random velocity. Since the random velocities seem to be observable, by measuring the radial velocities of individual stars, it follows that rotational velocities in some globular clusters should also be observable.

Another application of the ellipticity formula is to the calculation of the escape rate. In a rotating cluster the random velocities are lowered, because part of the internal motion appears in the systematic T_{rot} . The reduction of random velocities has two effects, which work in opposite directions. First, the ratio of escape velocity to rms velocity is increased, making it harder for a star to escape. This effect, which is complicated by the fact that a star is more likely to attain the escape velocity in the direction of rotation than in the opposite direction, has been discussed by Agekian (1958). He tabulates the escaping fraction of a Maxwellian distribution as a function of the ratio of rotational and random velocities. Agekian's z is equal to $\{\frac{1}{2}[(T/T_{\text{rot}}) - 1]^{-1}\}^{1/2}$; hence for a typical flattened cluster, with $T = 3T_{\text{rot}}$, we find $z = 0.87$, and Agekian's Table 1 shows that the escaping fraction is reduced from 7.4×10^{-3} to 4.7×10^{-3} .

The second effect, which tends to increase the escape rate, is a shortening of the time of relaxation. The latter is proportional to the cube of the random velocity and is therefore shortened by a factor

$$(T_{\text{rand}}'/T)^{3/2}, \quad \text{or} \quad (1 - T_{\text{rot}}/T)^{3/2};$$

and the escape rate will be increased by the same

factor. For the cluster just discussed, where $T_{\text{rot}}/T = \frac{1}{3}$, this factor is 0.545; so the combined effect of both factors is to increase the escape rate by a factor $4.7/(7.4 \times 0.545) = 1.17$.

It thus appears that the rotations observed in globular clusters increase the rate of escape of stars, but only by a slight amount.

Finally, it should be noted that the results of this paper are in no way invalidated by the recent work of Lynden-Bell (1960), who describes a configuration in which a stellar system can rotate while remaining spherical. Lynden-Bell's model is one in which every star retains a constant energy and angular momentum, undisturbed by stellar encounters. Aside from the fact that his velocity distribution is so highly artificial, the introduction of stellar encounters in a real cluster

makes the velocity distribution tend toward isotropy and the results of the present paper then follow.

ACKNOWLEDGMENT

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NGC 5466*

JAMES CUFFEY

Goethe Link Observatory, Indiana University

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The well-resolved globular cluster NGC 5466 is shown to have a color-magnitude relation resembling those of M3 and other clusters of very different physical structure. The distance modulus 16.56 and the distance 20.5 kpc are derived. Absorption appears to be negligible. In the analysis of the plate residuals the 18 previously known variables are displayed conspicuously. A list of additional high-residual stars for future investigation as possible variables is given in the text. Three of them are definitely variables, and 22, suspects. The space distribution of the globular clusters north of galactic latitude 50° is discussed in order to test the hypothesis that the clusters form a physical group, rather than a random sample of the halo population of the Milky Way system. The evidence suggests this may be the case, but does not conclusively establish it. Improvements in the distances for some of the objects are still needed to obtain the true relationship of these objects to each other and to the Milky Way system.

1. INTRODUCTION

AN unusually interesting high-latitude globular cluster with an extremely open, well-resolved structure, NGC 5466 was described by Shapley (1930) as a "loose globular cluster," like NGC 7492 and NGC 5053; he listed its concentration class as XII. Christie (1940) determined its integrated photographic apparent magnitude to be 10.39. Baade (1926) and Sawyer (1945) found a total of 18 variable stars. The present study, undertaken in 1953, is part of a survey presenting improved information on the globular clusters north of 50° galactic latitude, and examining the relationship of the clusters M3, M53, NGC 5053, NGC 5466, and NGC 4147 to each other and to the Milky Way (Cuffey 1954).

TABLE I. NGC 5466, photoelectric standards.

Star	<i>P</i>	<i>V</i>	<i>P-V</i>	Wt.	
3D 29° 2483	8.20	8.18	+0.02	10	A2
3D 29° 2493	7.98	7.05	+0.93	2	K0
A	14.38	14.02	+0.36	5	
B	14.81	14.19	+0.62	11	
C	16.60	16.87	-0.27	3	
D	18.52	18.02	+0.50	5	
E	16.93	16.31	+0.62	8	
F	14.18	13.94	+0.24	11	
G	15.03	13.91	+1.12	1	
1-4-12	15.80	15.41	+0.39	2	
4-3-1	16.82	16.50	+0.32	1	

Photometric results for NGC 5466 obtained by combining photoelectrically measured standard stars and photographic iris photometer measures are presented here. Photoelectric magnitudes for the standard stars, obtained with a refrigerated 1P21 photometer and the 100-inch Mt. Wilson reflector, are summarized in Table I. They were reduced to the *P, V* system represented in the photoelectric magnitudes determined by W. A. Baum for stars in Selected Areas 57 and 68. I am indebted to Dr. Baum for his permission to use these

values in advance of publication. A similar system by Eggen (1955) was used for reduction of zero-point observations made photoelectrically with the 36-inch reflector of the Goethe Link Observatory. The filters used with both telescopes were similar in transmission properties to those used by the *B, V* system of Johnson and Morgan. Thus the magnitudes in Table I may be expected to differ from the *B, V* system mainly by the difference in zero point between the *P* and *B* magnitude systems. It is likely that the photometric system adhered to in the present paper is related to the *B, V* system by the formula suggested by Baum,

$$B - V = 0.92(P - V) + 0.16,$$

although no extensive effort was made to derive the relation independently.

Offset guiding was used in measuring the faintest stars. Four one-minute deflections of star plus sky, along with four similar deflections on sky alone comprise a single observation of unit weight in Table I.

TABLE II. NGC 5466, Plate material 100-inch Mt. Wilson reflector.

	No.	Aperture (inches)	Exposure (minutes)	Date (1953)	Quality
Blue series	H18C	58	45	Apr. 12	exc.
	31	84	40	Apr. 14	exc.
	35	84	40	May 3	good
	38	84	10	May 3	good
	47	84	40	May 4	exc.
	62	58	44	May 6	fair
	64	58	60	May 7	good
	67	58	60	May 7	good
	68	58	60	May 7	fair
Yellow series	H17C	58	60	Apr. 12	exc.
	30	84	40	Apr. 14	exc.
	32	84	35	Apr. 14	exc.
	36	84	40	May 3	good
	37	84	10	May 3	good
	48	84	40	May 4	exc.
	54	84	25	May 4	good
	61	58	60	May 6	exc.
	65	58	60	May 7	exc.
	66	58	60	May 7	exc.
	69	58	38	May 7	poor

* Publications of the Goethe Link Observatory, Indiana University, No. 43.

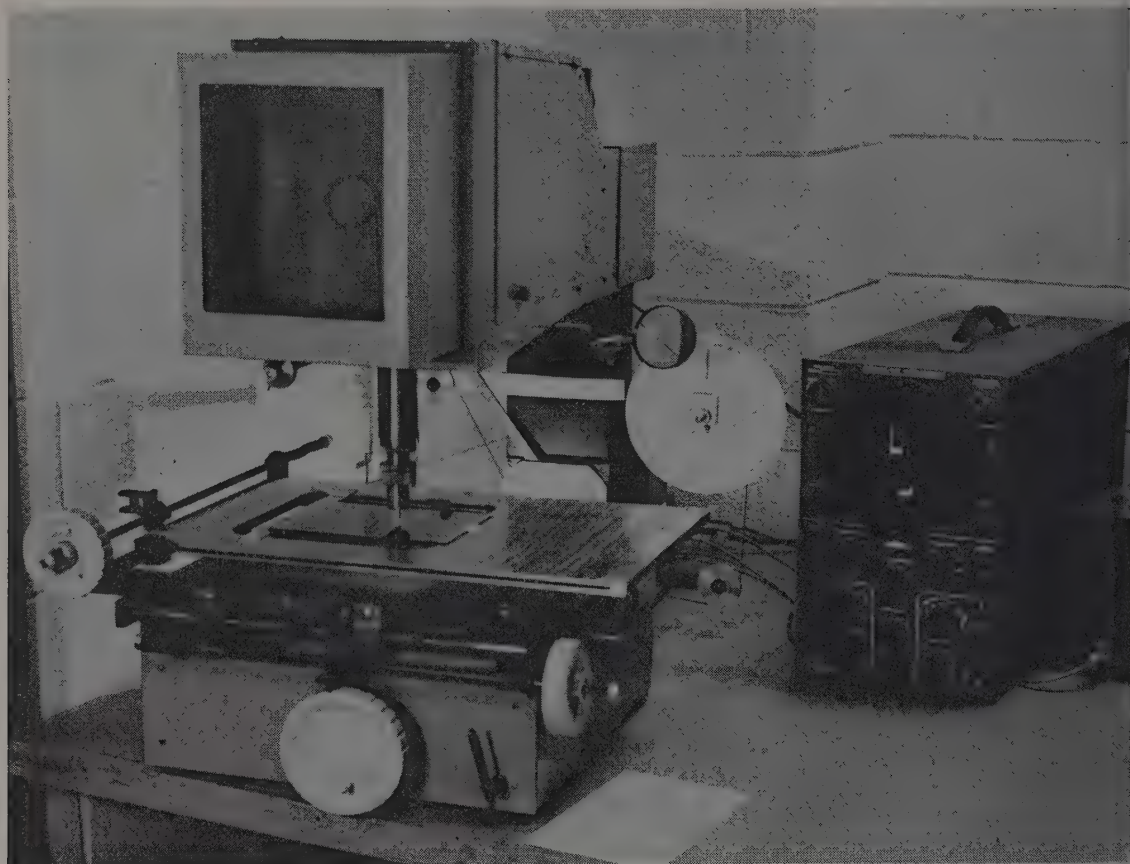


FIG. 1. Iris photometer, Indiana University.

The photographic observations, summarized in Table II, consist of a series of plates taken with the 100-inch reflector at the Mt. Wilson Observatory by the author as guest investigator in 1953. Diaphragms of 84 and 58 inches aperture were used in order to minimize field errors and improve the image quality for better resolution. The yellow plates were Eastman Spectroscopic 103aD, exposed through a GG 14 filter cutting off wavelengths shorter than 5000 Å. The blue plates were Eastman Spectroscopic IIaO exposed with a WG 2 filter to eliminate ultraviolet light beyond 3600 Å. A GG-13 filter, which cuts off the ultraviolet beyond 3800 Å was used in the photoelectric work, and in some additional photographic calibrations with the 36-inch telescope at the Goethe Link Observatory.

Figure 1 shows the iris photometer used for measuring the photographic plates. Designed by the author and built in the Astronomy Department machine shop at Indiana University by Marion Todd, it resembles an instrument described previously (Cuffey 1956). Improvements included a larger viewing screen, and specially built iris which gave a closer approach to linearity in the reduction curves for the fainter stars

than did the commercial iris used in the original model.

The form of the calibration curves for the iris photometer was established by measurements of 100-inch reflector plates of SA57 and 68, and plotting iris reading against the photoelectric magnitudes. The 16 plates listed by Cuffey (1958) were used. In general, the reduction curves are very smooth and resemble those of Fig. 2 in the above reference, but with improved linearity for the fainter stars. Since the general nature of the iris reading-magnitude relation was obtained from this study, adequate numbers of stars for the photographic reduction curves were easily obtained by interpolation between the photoelectric standards. Results summarizing the complete data adopted for the photographic standard stars are given in Table III. Magnitudes and colors of stars in NGC 5466 are listed in Table IV. The star charts, Figs. 2 and 3, show the method used for star designation. A pattern of four sectors and five concentric rings is superimposed upon the cluster. To illustrate, the designation 2-3-17 refers to the star 17 in sector 2 of ring 3 in Fig. 2. Figure 3 shows the central region, ring 1, only. Probable errors of the catalogued values are in Table V and are based

upon analysis of plate residuals to be discussed later in Sec. 3, Table VIIIA.

2. THE COLOR-MAGNITUDE RELATION

The color-magnitude relation for NGC 5466, shown in Figs. 4 and 5, closely resembles the corresponding relations in M3 (Sandage and Johnson 1956) and M53

(Cuffey 1958), a fact which is extremely interesting in view of the unusually open, sparsely populated structure of NGC 5466 compared with the highly concentrated very richly populated structures of M3 and M53. The 18 known variable stars, indicated by the circled points, all occur on the horizontal branch. The red-giant branch, and the branch containing the blue stars are

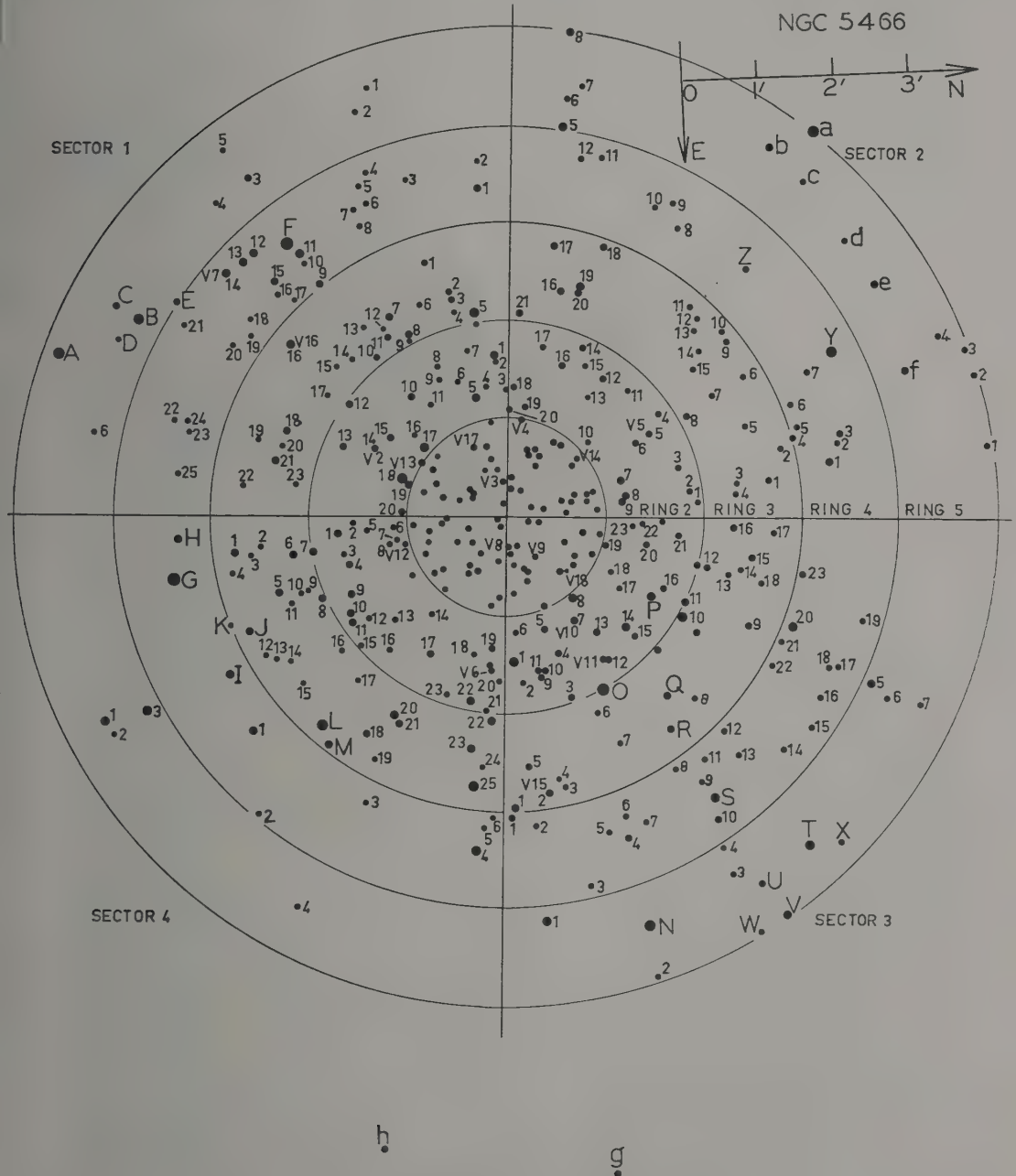


FIG. 2. NGC 5466, star chart.

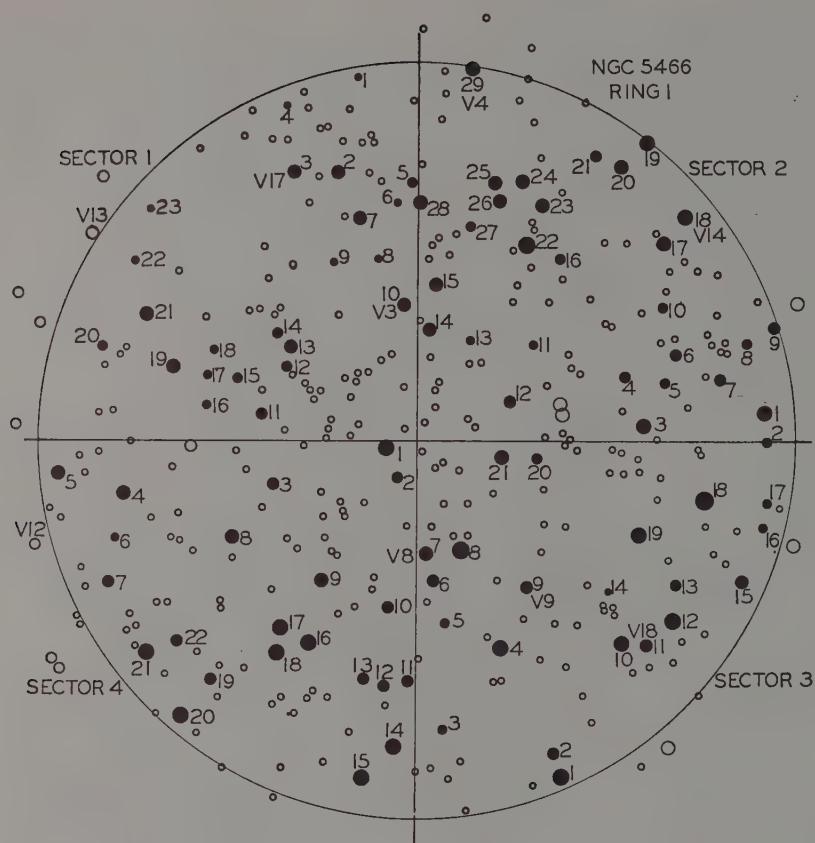


FIG. 3. NGC 5466, chart of central region only.

very well defined. One extremely blue star, 3-4-12, with the color index -0.49 is present, and resembles the very blue stars found by Sandage in M3. Fainter than $V=18.2$ the photometric results are based upon

extrapolation of the sequences, and open circles are plotted to indicate their tentative nature. The open squares show observations of the integrated colors of small areas between individually distinguishable images

TABLE III. NGC 5466, standard stars.

No.	P	V	P-V	No.	P	V	P-V
A ^a	14.43	14.05	+0.38	V	16.25	15.00	+1.25
B ^a	14.81	14.19	+0.62	W	17.80	17.51	+0.29
C ^a	16.66	16.88	-0.22	X	18.54	18.00	+0.54
D ^a	18.55	18.04	+0.51	Y	15.15	14.11	+1.04
E ^a	16.86	16.21	+0.65	Z	18.07	17.56	+0.51
F ^a	14.31	14.06	+0.25	a	14.93	13.68	+1.25
G ^a	14.96	13.63	+1.33	b	17.59	17.11	+0.48
H	16.65	16.80	-0.15	c	19.62	18.61	+1.01
I	16.37	15.72	+0.65	d	19.17	18.25	+0.92
J	16.72	17.03	-0.31	e	17.22	16.53	+0.69
K	18.61	18.06	+0.55	f	16.97	16.34	+0.63
L	14.67	14.76	-0.09	g	14.35	13.24	+1.11
M	18.25	17.80	+0.45	h	16.40	15.83	+0.57
N	14.79	13.58	+1.21	1-4-12 ^a	15.84	15.47	+0.37
O	14.63	14.21	+0.42	4-3-1 ^a	16.79	16.45	+0.34
P	15.12	14.00	+1.12	1-4-9	17.75	17.35	+0.40
Q	17.02	16.41	+0.61	1-4-16	19.14	18.54	+0.60
R	16.66	16.85	-0.19	1-4-17	18.64	18.11	+0.53
S	15.62	14.79	+0.83	3-4-21	18.42	17.96	+0.46
T	15.72	15.18	+0.54	3-4-22	19.58	18.61	+0.97
U	17.22	16.76	+0.46				

^a Photoelectric standard star.

TABLE IV. NGC 5466—catalogue of stars.

No.	P	V	P-V	No.	P	V	P-V	No.	P	V	P-V
S1R1				S1R4				S2R2			
1	18.01	17.56	+ .45	1	17.33	16.78	+ .55	1	16.85	16.20	+ .65
2	16.54	16.68	- .14	2	19.13	18.63	+ .50	2	17.42	16.90	+ .52
3	16.43	16.33	+ .10	3	19.58	18.95	+ .63	3	16.92	16.28	+ .64
4	18.58	18.03	+ .55	4	18.84	18.32	+ .52	4	16.63	16.89	- .26
5	17.15	16.68	+ .47	5	18.81	18.41	+ .40	5	16.79	16.64	+ .15
6	18.27	17.84	+ .43	6	18.74	18.23	+ .51	6	17.51	17.01	+ .50
7	16.59	16.87	- .28	7	18.81	18.26	+ .55	7	16.46	16.59	- .13
8	18.03	18.21	- .18	8	19.36	18.79	+ .57	8	16.59	16.86	- .27
9	18.60	18.11	+ .49	9	17.73	17.32	+ .41	9	15.77	14.96	+ .81
10	16.65	16.62	+ .03	10	18.48	17.96	+ .52	10	17.94	17.48	+ .46
11	17.76	17.28	+ .48	11	16.61	16.78	- .17	11	18.93	18.67	+ .26
12	16.40	16.51	- .11	12	15.84	15.46	+ .38	12	15.54	14.66	+ .88
13	15.27	14.39	+ .88	13	16.20	15.42	+ .78	13	18.06	17.59	+ .47
14	16.42	16.71	- .29	14	16.69	16.62	+ .07	14	16.57	16.74	- .17
15	17.89	17.44	+ .45	15	17.63	17.11	+ .52	15	18.75	18.19	+ .56
16	18.81	18.28	+ .53	16	19.02	18.54	+ .48	16	16.54	16.74	- .20
17	18.87	18.41	+ .46	17	18.66	18.11	+ .55	17	15.72	14.97	+ .75
18	18.67	18.14	+ .53	18	19.67	19.02	+ .65	18	16.74	16.51	+ .23
19	16.07	15.31	+ .76	19	19.44	18.82	+ .62	19	17.39	16.88	+ .51
20	16.91	16.29	+ .62	20	19.36	18.76	+ .60	20	17.08	16.52	+ .56
21	16.17	15.43	+ .74	21	18.76	18.19	+ .57				
22	17.88	17.39	+ .49	22	17.90	17.39	+ .51	S2R3			
23	19.09	18.78	+ .31	23	18.03	17.55	+ .48	1	16.63	16.85	- .22
S1R2				24	19.39	18.76	+ .63	2	16.44	16.07	+ .37
1	16.63	16.79	- .16	25	19.52	18.87	+ .65	3	17.45	16.91	+ .54
2	18.38	17.92	+ .46	F	14.33	14.11	+ .22	4	18.41	17.89	+ .52
3	16.56	16.80	- .24	S1R5				5	18.19	17.69	+ .50
4	18.64	18.10	+ .54	1	17.62	17.27	+ .35	6	18.18	17.71	+ .47
5	15.96	15.63	+ .33	2	16.61	16.73	- .12	7	18.48	18.00	+ .48
6	18.14	17.68	+ .46	3	16.69	16.91	- .22	8	16.61	16.79	- .18
7	18.44	17.97	+ .47	4	18.84	17.79	+1.05	9	17.20	16.64	+ .56
8	18.83	18.39	+ .44	5	19.40	18.87	+ .53	10	19.17	18.72	+ .45
9	17.70	17.24	+ .46	6	19.41	18.87	+ .54	11	16.61	16.80	- .19
10	17.13	16.54	+ .59	A	14.45	14.05	+ .40	12	19.16	18.64	+ .52
11	18.55	18.06	+ .49	B	14.80	14.19	+ .61	13	19.32	18.74	+ .58
12	15.56	14.65	+ .91	C	16.65	16.87	- .22	14	18.95	18.37	+ .58
13	16.62	16.82	- .20	D	18.56	18.05	+ .51	15	18.80	18.21	+ .59
14	16.69	16.56	+ .13	E	16.85	16.20	+ .65	16	16.51	16.64	- .13
15	14.85	13.56	+1.29	S2R1				17	16.58	16.62	- .04
16	18.03	17.52	+ .51	1	16.58	16.90	- .32	18	17.62	17.14	+ .48
17	15.46	14.54	+ .92	2	18.08	17.62	+ .46	19	15.37	14.42	+ .95
18	15.38	14.51	+ .87	3	16.52	16.73	- .21	20	16.60	16.38	+ .22
19	16.18	15.82	+ .36	4	17.58	17.16	+ .42	21	16.64	16.90	- .26
20	17.27	16.71	+ .56	5	17.74	17.26	+ .48	S2R4			
13	16.55	16.63	- .08	6	18.09	17.65	+ .44	1	16.62	16.85	- .23
S1R3				7	17.00	16.38	+ .62	2	19.06	18.47	+ .59
1	17.99	17.52	+ .47	8	17.60	17.11	+ .49	3	17.76	17.27	+ .49
2	17.89	17.43	+ .46	9	17.50	17.01	+ .49	4	16.72	16.05	+ .67
3	18.47	18.01	+ .46	10	18.18	17.75	+ .43	5	19.22	18.62	+ .60
4	18.58	18.08	+ .50	11	17.67	17.31	+ .36	6	18.15	17.67	+ .48
5	16.56	16.70	- .14	12	17.74	17.25	+ .49	7	19.12	18.57	+ .55
6	18.10	17.61	+ .49	13	18.80	18.51	+ .29	8	19.19	18.65	+ .54
7	16.78	16.13	+ .65	14	16.70	16.37	+ .33	9	19.11	18.66	+ .45
8	16.47	16.56	- .09	15	16.30	15.66	+ .64	10	18.73	18.19	+ .54
9	18.31	17.84	+ .47	16	17.35	16.81	+ .54	11	18.65	18.11	+ .54
10	17.78	17.29	+ .49	17	16.82	16.23	+ .59	12	18.86	18.40	+ .46
11	17.47	16.95	+ .52	18	16.46	16.35	+ .11	Y	15.13	14.10	+1.03
12	18.51	17.99	+ .52	19	16.57	16.80	- .23	Z	18.10	17.61	+ .49
13	18.83	18.28	+ .55	20	16.43	16.56	+ .13	S2R5			
14	18.82	18.30	+ .52	21	17.02	16.44	+ .58	1	18.69	18.05	+ .64
15	19.12	18.58	+ .54	22	15.20	14.01	+1.19	2	19.18	18.61	+ .57
16	16.52	16.52	.00	23	16.07	15.34	+ .73	3	19.64	18.98	+ .66
17	18.99	18.51	+ .48	24	16.56	16.71	- .15	4	19.41	18.72	+ .69
18	16.37	15.93	+ .44	25	16.60	16.41	+ .19	5	16.79	16.12	+ .67
19	19.11	18.67	+ .44	26	16.45	15.76	+ .69	6	17.68	17.31	+ .37
20	18.85	18.40	+ .45	27	18.41	18.31	+ .10	7	19.06	18.58	+ .48
21	16.68	16.94	- .26	28	16.55	16.72	- .17	8	16.31	15.87	+ .44
22	19.51	18.91	+ .60	29	16.82	16.83	- .01	a	14.91	13.68	+1.23
23	18.56	18.07	+ .49					b	17.60	17.13	+ .47

TABLE IV. (Continued)

No.	P	V	P-V	No.	P	V	P-V	No.	P	V	P-V
c	19.29	18.66	+ .63	17	18.81	18.26	+ .55	2	17.36	16.81	+ .55
d	19.04	18.30	+ .74	18	18.79	18.26	+ .53	3	18.55	18.04	+ .51
e	17.21	16.53	+ .68	O	14.63	14.21	+ .42	4	17.56	17.06	+ .50
f	16.97	16.33	+ .64	Q	17.02	16.41	+ .61	5	18.44	17.92	+ .52
				R	16.66	16.85	- .19	6	18.94	18.44	+ .50
								7	18.49	17.99	+ .50
	S3R1				S3R4			8	16.72	16.08	+ .64
1	15.83	15.00	+ .83	1	17.49	16.98	+ .51	9	16.82	16.17	+ .65
2	18.01	17.56	+ .45	2	18.50	18.03	+ .47	10	16.63	16.86	- .23
3	18.80	18.28	+ .52	3	19.30	18.75	+ .55	11	16.25	15.68	+ .57
4	15.47	14.56	+ .91	4	16.52	15.83	+ .69	12	18.63	18.07	+ .56
5	18.75	18.21	+ .54	5	18.99	18.50	+ .49	13	18.84	18.29	+ .55
6	17.89	17.43	+ .46	6	19.06	18.50	+ .56	14	18.28	17.81	+ .47
7	16.90	16.65	+ .25	7				15	18.24	17.76	+ .48
8	16.54	16.74	- .20	8	18.60	18.25	+ .35	16	16.97	16.38	+ .59
9	16.75	16.61	+ .14	9	18.70	18.14	+ .56	17	16.13	15.39	+ .74
10	15.22	14.43	+ .79	10	17.98	17.48	+ .50	18	18.62	18.10	+ .52
11	16.57	16.59	- .02	11	18.91	18.40	+ .51	19	17.06	16.48	+ .58
12	15.75	14.90	+ .85	12	17.22	17.71	- .49	20	18.11	17.65	+ .46
13	16.72	16.52	+ .20	13				21	16.61	16.41	+ .20
14	18.17	18.08	+ .09	14	19.29	18.65	+ .64	22	14.87	13.60	+ .27
15	16.71	17.02	+ .69	15	19.68			23	18.36	17.92	+ .44
16	18.29	17.83	+ .46	16	19.65	18.37	+1.28	V 6	16.82	16.45	+ .37
17	17.69	17.32	+ .37	17	18.73	18.20	+ .53	V 12	16.58	16.68	- .10
18	15.12	14.38	+ .74	18	19.44	18.75	+ .69				
19	16.57	16.81	- .24	19	17.97	17.81	+ .16		S4R3		
20	18.45	17.98	+ .47	20	16.61	16.85	- .24	1	16.80	16.45	+ .35
21	17.36	16.84	+ .52	21	18.41	17.92	+ .49	2	18.22	17.74	+ .48
				22	19.24	18.64	+ .60	3	19.44	18.76	+ .68
	S3R2			23	18.08	17.56	+ .52	4	19.36	18.79	+ .57
1	15.45	14.51	+ .94	S	15.62	14.78	+ .84	5	16.69	16.97	- .28
2	18.51	17.99	+ .52					6	16.61	16.86	+ .25
3	16.37	15.66	+ .71		S3R5			7	16.30	15.58	+ .72
4	17.59	17.09	+ .50	1	16.71	16.58	+ .13	8	17.92	17.47	+ .45
5	17.00	16.39	+ .61	2	19.00	17.50	+1.50	9	19.32	18.86	+ .46
6	18.15	17.69	+ .46	3	18.95	18.37	+ .58	10	19.67	18.90	+ .77
7	16.78	16.54	+ .24	4	19.21	18.49	+ .72	11	19.02	18.44	+ .58
8	15.86	15.06	+ .80	5	16.69	16.98	- .29	12	19.44	18.79	+ .65
9	16.94	16.36	+ .58	6	19.03	18.11	+ .92	13	19.60	18.94	+ .66
10	16.62	16.89	- .27	7	18.94	18.46	+ .48	14	19.19	18.63	+ .56
11	16.83	16.21	+ .62	N	14.79	13.57	+1.22	15	19.46	18.87	+ .59
12	16.74	16.08	+ .66	T	15.72	15.19	+ .53	16	18.91	18.39	+ .52
13	15.48	14.55	+ .93	U	17.21	16.76	+ .45	17	19.16	18.54	+ .62
14	17.72	17.25	+ .47	V	16.24	15.01	+1.23	18	15.78	14.93	+ .85
15	18.12	17.65	+ .47	W	17.80	17.53	+ .27	19	18.77	18.26	+ .51
16	17.31	16.75	+ .56	X	18.52	18.02	+ .50	20	15.48	14.54	+ .94
17	18.88	18.34	+ .54					21	16.05	15.40	+ .65
18	18.68	18.75	- .07		S4R1			22	16.95	16.33	+ .62
19	15.89	15.19	+ .70	1	16.58	16.72	- .14	23	16.66	16.94	- .28
20	16.55	16.80	- .25	2	17.60	17.12	+ .48	24	19.50	18.85	+ .65
21	18.06	17.59	+ .47	3	16.46	16.56	- .10	25	15.44	14.58	+ .86
22	18.37	18.87	+ .50	4	15.87	15.09	+ .78	J	16.71	17.04	- .33
23	18.68	17.81	+ .87	5	15.50	14.67	+ .83	L	14.72	14.74	- .02
V 11	16.75	16.69	+ .06	6	18.89	18.39	+ .50	M	18.25	17.79	+ .46
P	15.11	14.00	+1.11	7	16.99	16.36	+ .63				
				8	16.39	16.02	+ .37		S4R4		
	S3R3			9	16.22	15.49	+ .73	1	16.85	16.17	+ .68
1	16.79	16.11	+ .68	10	16.51	16.70	- .19	2	18.89	18.36	+ .53
2	16.61	16.59	+ .02	11	16.64	16.46	+ .18	3	19.35	18.66	+ .69
3	18.14	17.64	+ .50	12	16.94	16.37	+ .57	4	18.03	17.63	+ .40
4	18.96	18.45	+ .51	13	16.56	16.83	- .27	5	19.42	18.76	+ .66
5	17.83	17.34	+ .49	14	16.83	16.19	+ .64	6	18.96	18.41	+ .55
6	18.88	18.43	+ .45	15	16.52	15.82	+ .70	G	14.95	13.63	+1.32
7	18.64	18.09	+ .55	16	15.57	14.75	+ .82	H	16.64	16.80	- .16
8	17.87	17.38	+ .49	17	16.38	15.73	+ .65	I	16.47	15.77	+ .70
9	16.67	16.88	- .21	18	16.33	15.75	+ .58	K	18.60	18.05	+ .55
10	15.39	14.41	+ .98	19	17.75	17.30	+ .45				
11	16.57	15.88	+ .69	20	16.70	16.07	+ .63		S4R5		
12	17.48	16.97	+ .51	21	16.10	15.34	+ .76	1	16.56	15.89	+ .67
13	19.12	18.53	+ .59	22	16.97	16.46	+ .51	2	19.10	18.56	+ .54
14	19.42	18.84	+ .58					3	16.70	16.99	- .29
15	17.21	16.64	+ .57		S4R2			4	18.74	18.21	+ .53
16	16.60	16.84	- .24	1	16.59	16.85	- .26				

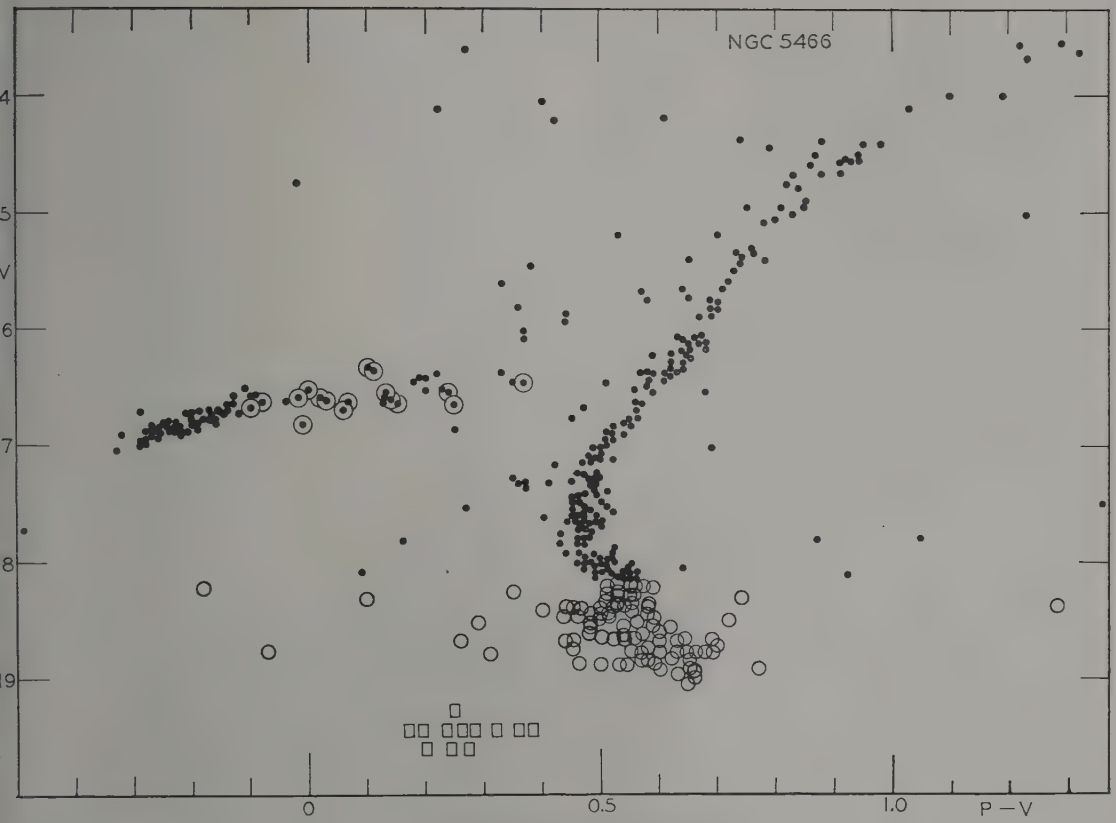


FIG. 4. NGC 5466, color-magnitude relation.

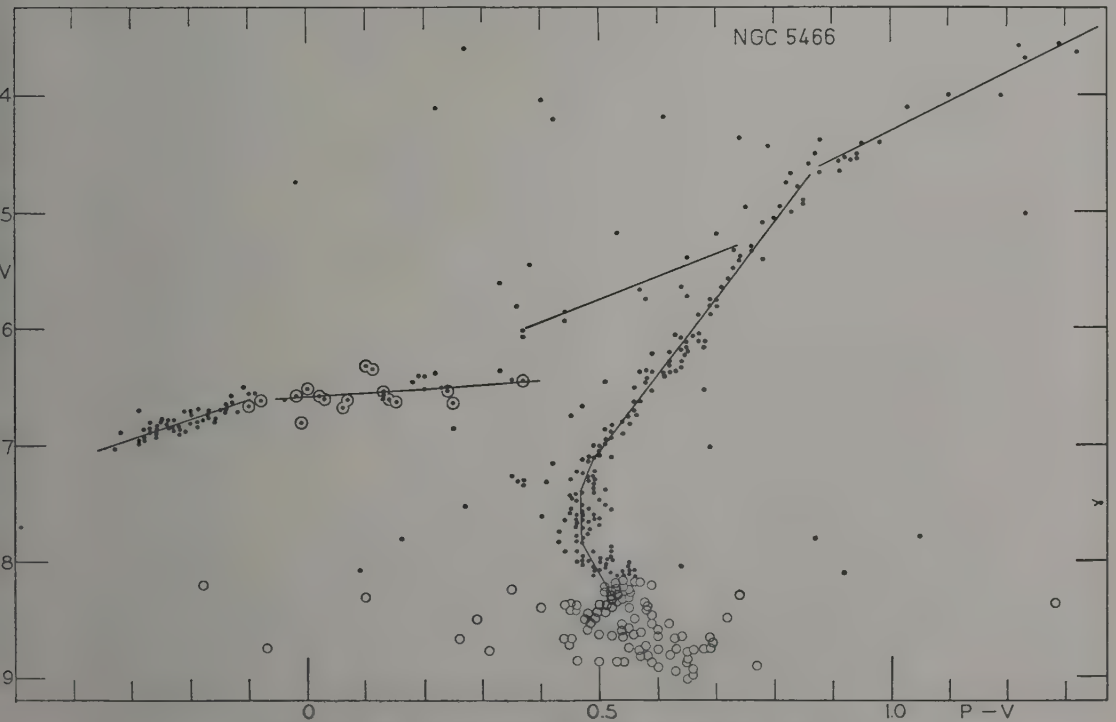


FIG. 5. NGC 5466, color-magnitude relation, with branches indicated.

TABLE V. Probable errors of catalogue magnitudes.

Magnitude interval	P	V	$P-V$
13.5-17.0	± 0.010	± 0.009	± 0.013
17.0-18.2	0.011	0.012	0.016
18.2-18.7	0.016	0.013	0.021
18.7-19.7	0.028	0.019	0.034

TABLE VI. Photoelectric integrated colors of areas containing very faint stars only.

Area	Diaphragm Size (mm)	P	V	$P-V$
a	0.6	17.84	17.65	0.19
b	0.6	16.85	16.59	0.26
y	0.6	17.54	17.16	0.38
e	0.6	19.02	18.76	0.26
y	0.4	17.73	17.49	0.24
y	0.6	16.42	16.10	0.32
y	1.2	14.93	14.76	0.17
y	2.2	13.35	12.99	0.36
b	0.4	17.34	17.07	0.27
b	0.6	15.80	15.60	0.20
b	1.2	14.73	14.48	0.25
b	2.2	13.68	13.42	0.26

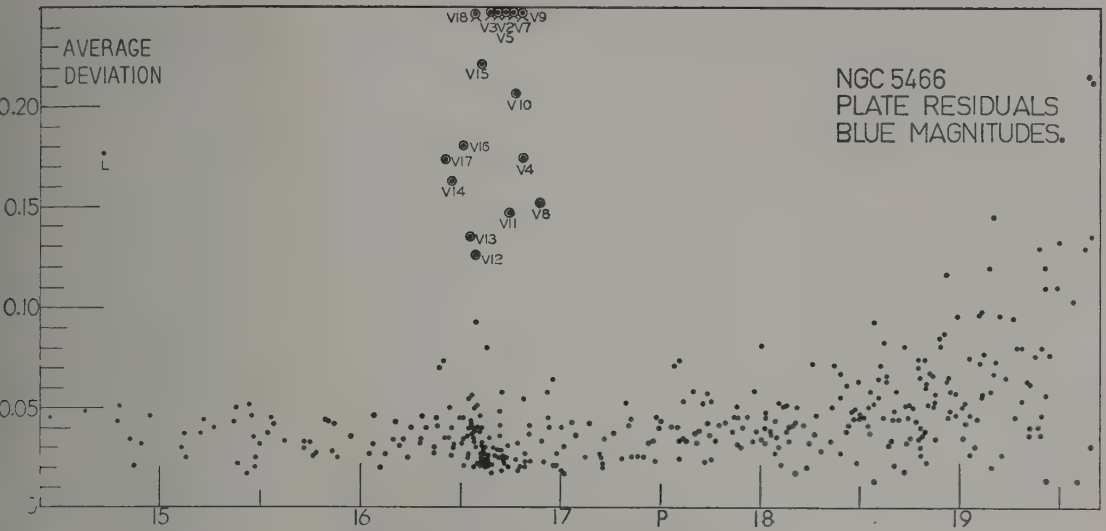
near the cluster's nucleus. Because individual stars are difficult to observe photoelectrically fainter than the 19th magnitude, this attempt to derive integrated colors for stars fainter than those measured individually seemed of interest. Four areas near the center of the cluster in ring 1, were chosen, in which no stars bright enough for individual measurement appeared on the photographic chart. Photoelectric measures of these areas were made with several different diaphragm openings. Thus the integrated color refers to the light from a number of faint stars whose light entered the diaphragm at the same time. The results are in Table VI. First, all four areas were measured with the smallest diaphragm, whose size, when projected on the photographic chart, assured that no light from individually visible images entered the diaphragm. Next, two of the areas were observed with successively larger diaphragms, only the largest of which might have been suspected of including light from individually distinguishable images. The average integrated color of

stars fainter than the limiting magnitude in Fig. 4 is 0.26, and is evidently not sensitive to observational difficulties associated with varying diaphragm size and interference of visible images. Obviously the points plotted as open squares in Fig. 4 do not show the trend of the color-magnitude relation, since the luminosity function, which is unknown, would be necessary for a proper interpretation of the meaning of the integrated color in terms of the color-magnitude relation for the stars beyond the observed limits.

Distance estimates for NGC 5466 were made by



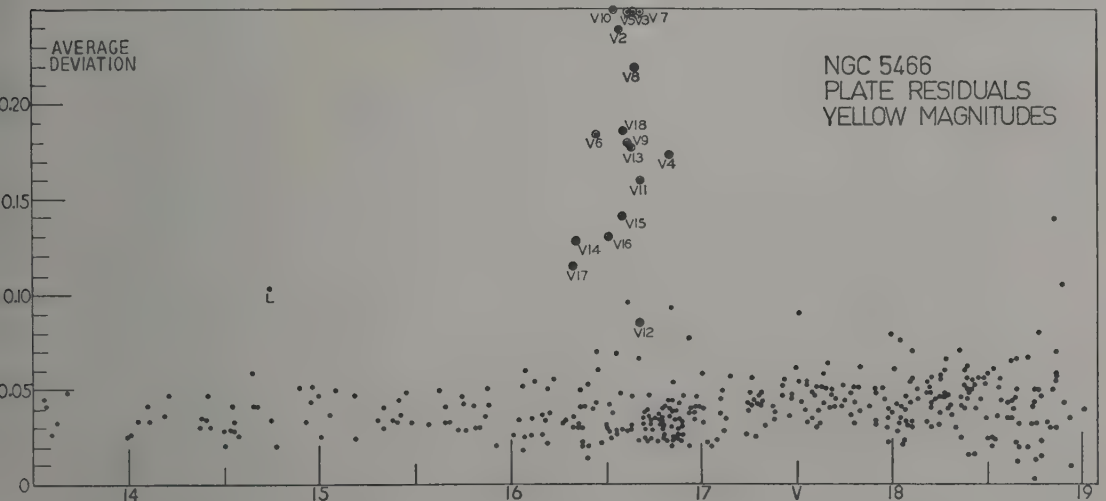
FIG. 6. NGC 5466, areas in color-magnitude relation.

FIG. 7. Plate residuals as a function of P magnitude.

comparing the branches outlined in Fig. 5 with the corresponding branches in M3. For M3, the modulus 16.67 was adopted (Sandage and Johnson 1956). Very little absorption is to be expected in the high galactic latitude involved and the extreme blueness of some of the stars in both clusters is evidence of its absence. Plotting various parts of the color-magnitude relation and using the designations of Fig. 6, we obtain the following values of the difference in distance modulus between NGC 5466 and M3: RG , 0.85; R , 0.94; H , 0.93; B , 0.87. The known variables give 0.91. Taking a weighted mean, we obtain the adopted value 0.89, which results in the distance modulus 16.56 for NGC 5466. The distance is then 20.5 kpc.

3. VARIABLE STARS AND PROBABLE ERRORS

Most of the catalogued yellow magnitudes in Table IV are based upon the average of 11 measures per star, that being the number of plates which gave measurable images for all stars brighter than 18.5. Similarly, the blue magnitudes come from an average of nine measures per star. The plates were taken during two observing sessions lasting three days each and separated by 22 days. They should show up conspicuously stars with short-period variability. In order to find any new variable stars present in the data on which Table IV is based, the residuals of the individual measures from the average value were computed for each star. The

FIG. 8. Plate residuals as a function of V magnitude.

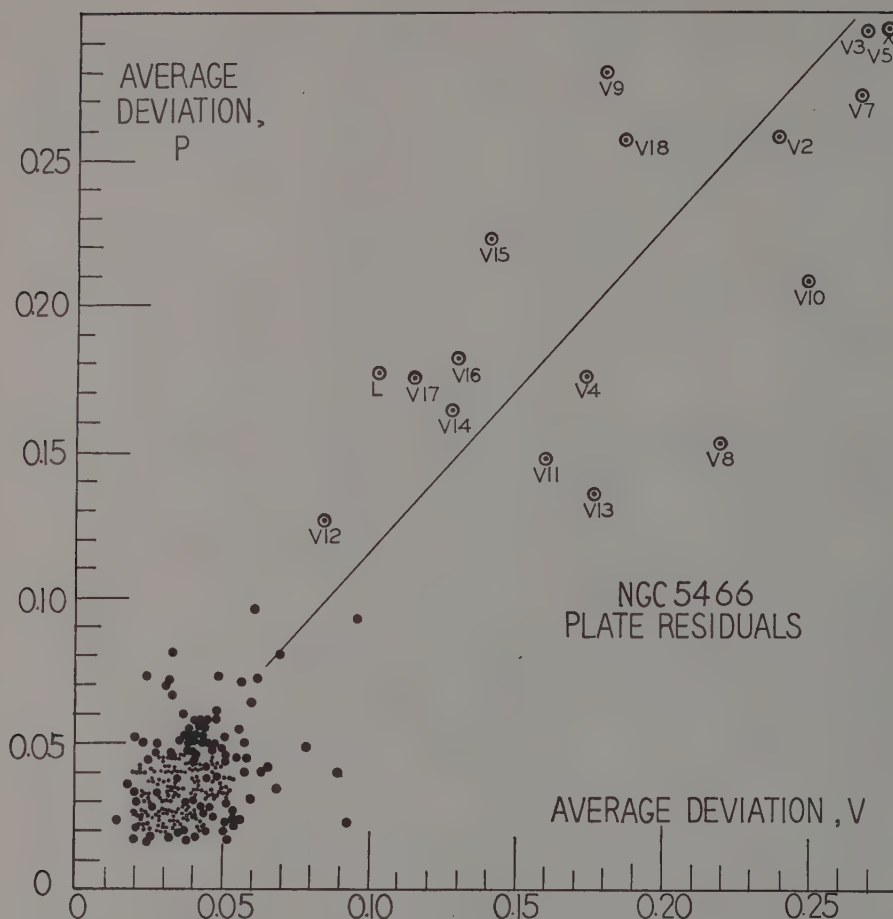


FIG. 9. Plate residuals P related to plate residuals V , for stars brighter than 18.0 only.

average of the absolute values of these residuals is customarily referred to as the average deviation, A.D. Variability is indicated by an unusually large value of the average deviation. Ability to detect variables of small amplitude depends, however, upon how large the errors of measurement are. For this reason, Figs. 7 and 8 and Table VIIIA are of fundamental importance. Here, the average deviations in yellow and blue light are plotted against the corresponding V and P magnitudes. Known variables are circled and labeled for identification. Without exception, they come from the H branch in Fig. 6, and occur near $V=16.5$.

Figures 7 and 8, and Table VIIIA were used in deriving the probable errors of the magnitudes and colors tabulated in Table V. Well-known statistical relations, combined with the number of measurable images in each magnitude interval, were used. Known variables were omitted from the calculations in Table VIIIA, but included in Table VIIIB.

To search for new variable stars, diagrams similar to Figs. 7 and 8 were plotted for each of the areas of the color-magnitude relation in Fig. 6. An additional diagram, Fig. 9, showing whether or not for a given star,

high yellow residual was confirmed by high blue residual, was also consulted. Faint stars, whose inherently larger errors of measurement would obscure the desired information, are omitted from Fig. 9.

The results of the search for new variable stars are summarized in Table VII. Standard star L, a white giant located well above the horizontal branch at $V=14.74$, $P-V=-0.02$, has large residuals in both blue and yellow light; its designation as variable number 19 is suggested. It is not listed in the general catalogue of variable stars by Kukarkin, Parenago, Efremov, and Kholopov (1958). Star 2-3-17, with high residuals, and located in Region H of the color-magnitude relation is suggested for designation as variable number 20. Star 4-1-11, also in region H is suggested as variable number 21. Star 3-4-2 is suggested as variable number 22. It is quite red. Additional stars listed in Table VII are worthy of future investigation, but can only be regarded as suspects from the present study.

In order to determine whether stars of various regions of the color-magnitude relation showed a greater or smaller tendency toward small-range variation, dia-

TABLE VII. Variable stars and stars with high residuals. Average deviation of single observation. Stars brighter than $V=18.2$ only.

Star	A.D. <i>P</i>	A.D. <i>V</i>	C-M Region (Fig. 6)	Comments
7 1	...	...		Off chart
7 2	0.258	0.240	<i>H</i>	
7 3	0.295	0.270	<i>H</i>	Crowded, but resolved image
7 4	0.176	0.174	<i>H</i>	Blended image
7 5	0.328	0.300	<i>H</i>	
7 6	...	0.185	<i>H</i>	Poor resolution near to image
7 7	0.272	0.268	<i>H</i>	
7 8	0.153	0.220	<i>H</i>	
7 9	0.280	0.180	<i>H</i>	
7 10	0.208	0.250	<i>H</i>	
7 11	0.148	0.160	<i>H</i>	Poor resolution near to image
7 12	0.127	0.085	<i>H</i>	
7 13	0.136	0.177	<i>H</i>	
7 14	0.164	0.128	<i>H</i>	
7 15	0.223	0.141	<i>H</i>	
7 16	0.182	0.130	<i>H</i>	
7 17	0.175	0.115	<i>H</i>	
7 18	0.257	0.187	<i>H</i>	Poor, very close to bright image
3-17	0.177	0.103	<i>G</i>	
3-17	0.093	0.096	<i>H</i>	
5-2	0.096	0.061	<i>FR</i>	Very red
1-11	0.080	0.070	<i>H</i>	
1-6	0.072	0.062	<i>S</i>	Slight crowding of image
1-4	0.071	0.057	<i>FW</i>	Slightly blended image
3-7	0.049	0.079	<i>S</i>	
1-2	0.073	0.049	<i>R</i>	
1-22	0.064	0.060	<i>YR</i>	
2-16	0.040	0.090	<i>S</i>	
4-20	0.023	0.093	<i>B</i>	
1-1	0.081	0.033	<i>S</i>	
2-2	0.071	0.032	<i>S</i>	
4-21	0.067	0.033	<i>S</i>	
few additional stars with residuals smaller than those listed above, but larger than usual for stars of the same brightness are:				
1-12			<i>H</i>	
1-20			<i>H</i>	
5-1			<i>H</i>	
3-23			<i>VB</i>	
2-12			<i>RG</i>	
2-12			<i>R</i>	
1-5			<i>YR</i>	
4-6			<i>S</i>	
standard X				
5-1			<i>FS</i>	
5-6			<i>FR</i>	

grams similar to Figs. 7, 8, and 9 were plotted for each of the regions shown in Fig. 6. Table VIII summarizes the results. Evidently, subject to the uncertainties inherent in the probable errors of measurement, there is no reason to suppose that any of the areas contain stars with greater tendency toward small range variability

TABLE VIIIA. Average A.D. for single measurement as a function of magnitude, summarized from Figs. 7 and 8.

Magnitude interval	Average deviation <i>P</i>	Average deviation <i>V</i>
13.5-16.3	0.035	0.037
16.3-17.0	0.035	0.036
17.0-18.2	0.038	0.043
18.2-18.7	0.048	0.044
18.7-19.7	0.066	0.045

TABLE VIIIB. Average A.D. for single measurement relative to region of color-magnitude diagram.

Region	<i>P</i>	<i>V</i>
<i>G</i>	0.042	0.039
<i>RG</i>	0.035	0.036
<i>R</i>	0.032	0.037
<i>H</i>	0.133	0.125
<i>B</i>	0.033	0.033
<i>VB</i>	0.032	0.035
<i>Y</i>	0.039	0.040
<i>YR</i>	0.037	0.044
<i>S</i>	0.042	0.048
<i>FS</i>	0.061	0.045
<i>FW</i>	0.050	0.039
<i>FR</i>	0.075	0.047

than any other, except of course, the *H* branch and its known variables of conspicuously large range.

4. THE SPATIAL DISTRIBUTION OF THE CLUSTERS NORTH OF 50° GALACTIC LATITUDE

Improved distances are now available for most of the high-latitude globular clusters and we are in a position to draw some conclusions regarding their relationship to each other and to the Milky Way. To judge by their position in the sky, the clusters appear to form a definite group, although this is difficult to establish definitely from a statistical standpoint. The clusters north of 50° all lie inside a circular area of 700 square degrees, while if random distribution were involved, one might expect them to be distributed more evenly over the 3200 sq deg accessible to them. Thus they occupy only $\frac{1}{4}$ of the area of sky available to them on the basis of random distribution.

A more relevant analysis of their relationship must be based upon their distribution in space. Coordinates now available for the clusters are in Table IX. Figure 10 shows the space distribution of the clusters, projected on the *XZ* plane, relative to a cross section of the Milky

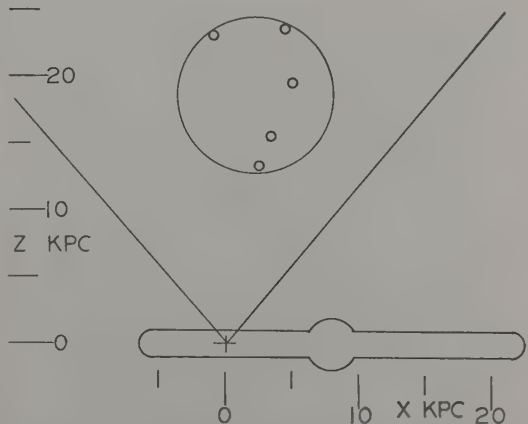


FIG. 10. Space distribution of globular clusters north of 50° galactic latitude.

TABLE IX. Coordinates of globular clusters north of 50° galactic latitude.

		1900		1	B	X	Y	Z	D
M3	5272	13 ^h 37.6	28°53	7°	78°	+2.31	+1.81	+13.3	13.6 kpc
M53	5024	13 08.0	18 42	305	79	+4.15	-1.94	+23.6	24.0
	5466	14 01.0	29 00	8	73	+4.86	+3.73	+19.6	20.5
	5053	13 11.5	18 13	309	78	+3.12	-1.14	+15.6	16.0
	4147	12 05.0	19 06	224	76	-1.07	-4.32	+22.97	23.4

Way system. Here, and also on a similar plot projecting them on the YZ plane, the entire group may be enclosed in a spherical volume whose radius is 6 kpc.

Thus the cluster group occupies only 860 cubic kiloparsecs, or only $\frac{1}{12}$ of the conical volume north of galactic latitude 50° out to a distance of 24 kpc, which one should consider accessible to them on the basis of random distribution in space. Thus the statistical material is by no means definitive, and improved distances for some of the clusters could alter the conclusion. One has the impression from Fig. 10 that the clusters form a definite group, too asymmetrically located relative to the Milky Way, and somewhat too far from the Milky Way plane, to be regarded as a typical part of the halo population.

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The Fornax Dwarf Galaxy. I. The Globular Clusters

PAUL W. HODGE*

*Harvard College Observatory, Cambridge Massachusetts, and Mount Wilson and Palomar Observatories,
Carnegie Institution of Washington, California Institute of Technology*

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Two new globular clusters have been found to belong to the Fornax dwarf galaxy. The properties and dimensions of the five known globular clusters are comparable to those of our galaxy. Measures of individual stars in each indicate that the magnitudes of their brightest stars are identical within 0.1 mag., but that the brightest stars of the main galaxy are 0.5 mag. brighter. The globular clusters have nearly ten times the projected star density of the main galaxy.

SHORTLY after Shapley's discovery (1938) of the nearby dwarf elliptical galaxy in Fornax, he published the positions of three globular clusters apparently associated with this galaxy (1939). Two of these clusters were investigated by Baade and Hubble (1939), who used the Mt. Wilson 100-inch reflector. Neither the 100-inch telescope nor Harvard's 60-inch reflector, used by Shapley, has a large enough field to photograph the entire galaxy on one plate. Therefore it was thought worthwhile to re-examine the Fornax dwarf with plates of the ADH Baker-Schmidt, which has both a large field and a faint magnitude limit. Two long-exposure ADH plates, taken without filter, were examined in 1957, and then a series of very long-exposure blue and visual ADH plates was taken of the Fornax galaxy when the writer was in South Africa in 1958. In addition, he has taken a few plates of the galaxy with the 48-inch Schmidt of the Palomar Observatory.

THE NEW CLUSTERS

In addition to the three previously known globular clusters, two new ones were found on the plates. All are listed and described in Table I. Figure 1 represents

TABLE I. Globular clusters of the Fornax dwarf galaxy.

Number	$\alpha(1950)$	$\delta(1950)$	Conc. class	Diam.
	2 ^h 35 ^m 0	-34° 23'	XI	0'.6
	2 36.6	-35 01	VIII	0.6
(NGC 1049)	2 37.8	-34 29	V	0.6
	2 38.1	-34 45	IV	0.4
	2 40.4	-34 21	III	0.5

aces a portion of a 75-minute exposure ADH plate, on which the globular clusters are identified.

Of the new clusters, No. 5 is the brighter and the nearer to the center of the galaxy. Its distance of 40' from the center places it just within the outermost contours of the star distribution of the galaxy, as determined from counts on the Schmidt plates. It lies outside the boundaries of the galaxy as determined by Shapley (1939) or Baade and Hubble (1939) from large-reflector

plates. Cluster No. 5 is very heavily concentrated towards its center, and appears nearly stellar on plates of the 24-inch Bruce camera.

The other new cluster, No. 1, is unusually open and poor in stars. It has a very irregular appearance, but is quite certainly a globular cluster, for its brightest stars are similar in magnitude and color to those of the other four globulars. Cluster No. 1 is 43' distant from the center of the Fornax galaxy and lies about 5' from the outermost portions of the galaxy traceable from star counts.

It seems unlikely that any further globular clusters will be found to be members of the Fornax dwarf. The sky within 2° of the center of the system was thoroughly searched on ADH plates with a limiting photographic magnitude of about 20, without additions to the present list.

A very faint object, just 7' north of cluster 4, was mentioned by Shapley (1939) as a possible cluster of the system. It is unresolved on all the Schmidt plates, and is probably rather bluer than the globular clusters. On 200-inch plates taken by Baade and kindly shown to the writer by Miss Swope, this object appears as a group of five stars of approximately 21st mag. They appear to have the color of the neighboring stars of this magnitude.

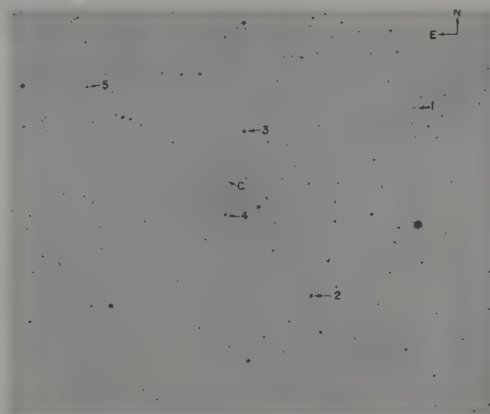


FIG. 1. The Fornax dwarf galaxy. The five globular clusters are numbered. The group of very faint stars is designated by C. From a blue photograph taken with the ADH Baker-Schmidt telescope.

* National Science Foundation Post-Doctoral Fellow.

DIAMETERS

Table I lists the angular diameters of the globular clusters as judged on the deepest Schmidt plates. Such estimates are useful in giving bases for rough comparisons. All of the clusters are seen to be very similar in size. If we accept Baade and Hubble's (1939) distance for the system as 180 kpc, the mean cluster diameter of 0.5' corresponds to 30 parsecs. This agrees well with sizes of globulars in the Galaxy, but is smaller than values for intergalactic tramp globulars (Burbidge and Sandage, 1958). It should be mentioned that Baade and Hubble's distance remains the best available estimate. The distance given by Allen (1956), 290 kpc, results from an incorrect application of the 1952 distance-scale revision which does not apply to the Fornax galaxy.

MAGNITUDES

From photographic transfers, Baade and Hubble (1939) were able to determine an approximate value of 19.67 for the photographic magnitude of the 6th brightest star in the globular NGC 1049. The writer has measured with an Eichner astrophotometer the brightest stars of all five objects to determine how well they agree. Because of the lack of a photoelectric sequence, approximate magnitudes were obtained using Baade and Hubble's magnitude for a zero point and sequences on other ADH plates for the slope of the calibration curve. Though not well calibrated, the present material is uniform, and can be used to detect differences in the level of the brightest stars of different clusters. Such a test is of considerable interest in the light of recent evidence (Sandage and Wallerstein 1960) that the brightest stars among globular clusters may differ considerably in magnitude, as a function of chemical composition. The magnitudes given in Table II show that for the five clusters of the Fornax system, the brightest stars are all very nearly the same, the difference being no greater than 0.1 mag. Crowded images prevented the detection of any possible smaller differences in brightness. However, the data easily show that differences as large as those discussed by Sandage and Wallerstein do not exist for the Fornax system globular clusters. This fact indicates that the globulars in Fornax are probably uniform in age and chemical composition, a condition which seems reasonable for such a uniform and featureless system as an elliptical galaxy.

COMPARISON WITH MAIN GALAXY

The brightest stars in the main galaxy itself are considerably (approximately 0.5 mag.) brighter, than any

TABLE II. Magnitudes of brightest stars in clusters.

Cluster	Magnitude (pg)
1	19.7
2	19.6
3 (NGC 1049)	19.6
4	19.7
5	19.6
main galaxy	19.1

stars of the globular clusters. This fact is important to the problem of determining distances to such objects if mean globular-cluster characteristics are applied to elliptical galaxies. The difference may be a consequence of the far greater population of the galaxy, where unusually bright stars are statistically more plentiful. Star counts indicate that to the approximate limiting magnitude $pg=19.9$, the Fornax galaxy contains nearly 10 000 stars, while the globular clusters each contain fewer than 20 to this limit. However, the luminosity function of M3 determined by Sandage (1954) is so steep at the bright end that a simple multiplication of it by 500 does not increase the number of stars sufficiently to raise the upper brightness limit by more than 0.1 mag. It seems necessary to conclude that the observed difference of 0.5 mag. is not a straightforward result of the greater population of the galaxy, but results from differences in the shapes or levels of the color-magnitude diagrams of clusters and galaxy.

A further conspicuous difference between the parent galaxy and its globular clusters is in their star densities. On a blue plate with the approximate faint limit of 19.9, the projected density of stars in the most dense portions of the Fornax galaxy is 9 stars per square minute, while that for the globular clusters averages 80 stars per square minute.

The Fornax dwarf, with its globular clusters, is an ideal object for studying differences between elliptical galaxies and globular clusters. The present work indicates that the differences are not trivial, and that color-magnitude diagrams of these objects are of great desirability.

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Possible M-Star Members of NGC 6838

C. B. STEPHENSON

Warner and Swasey Observatory, Case Institute of Technology, Cleveland, Ohio

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In the vicinity of the metal-rich globular or globularlike cluster NGC 6838, bands of titanium oxide have been found, on objective-prism plates, for six stars (one case previously known). Four of these stars are within one cluster radius of the center and fall at the upper end of the giant branch of the color-magnitude diagram. An objection to their cluster membership is that they require the diagram either to be abnormal or little reddened; but independent evidence already suggests the same problem for the color-magnitude diagram. No definite conclusions about cluster membership of the M stars can be drawn, but identification charts for them are furnished.

INTRODUCTION

AS was recently remarked by Sandage (1959), the presence or absence of titanium oxide in the oldest giant stars of globular clusters may be a good indication of metallic abundances there. Accordingly, a search for M giants in the metal-rich globular clusters of Morgan's list (1959) is of considerable interest. NGC 6838 is one of the most easily observed of these clusters and has been observed by the writer with objective-prism equipment in a search for M stars.

OBSERVATIONS

It has long been known that stars classified as M from the conventional blue spectral region also show bands of *TiO* which are detectable in the yellow-red at very low dispersion (cf. Morgan, Keenan, and Kellman 1943). The 5800–6900 Å region has been used for this purpose at the Warner and Swasey Observatory (Iwanowska and Wayman 1952, Velghe 1957, Nassau and Stephenson 1960) at a dispersion of ~ 1000 Å/mm, and it has been noted recently that the earliest M stars (M0–M2) are detectable in this way with greater certainty than in the infrared region (7000 Å–9000 Å) which has played so important a role in M-star surveys at this Observatory. The short, narrow spectra which are used for the red *TiO* identifications are, because of their small dimensions, well suited for study of the crowded images of a globular cluster, and consequently the 5800–6900 Å spectral region was utilized for the present survey. This spectral segment was isolated by means of Kodak 103a-F plates and a Schott OG2 filter in conjunction with the Warner and Swasey objective-prism equipment.

Magnitudes and color indices for stars in the cluster vicinity were kindly furnished to the writer by Dr. James Cuffey. These data, which were photographically determined with the aid of a photoelectrically established magnitude sequence (Cuffey 1959), indicate that the *TiO* band heading at $\lambda 6159$, which is the first distinctive feature to appear in the red spectra of type M, is detectable for early M stars as faint as *V* magnitude 4.0 on the plates used for the survey. The color-magnitude diagrams for this cluster published by Cuffey (1943) and by Becker (1954) show the giant

branch beginning at the twelfth magnitude. The $\lambda 6200$ *TiO* band is as readily detectable on the plates used as are the more familiar blue-green *TiO* bands at the fourfold greater dispersion used here in classifying spectra in the blue; hence the present test for *TiO* in the cluster was quite straightforward in principle. In fact, however, a few stars observed by Cuffey in the denser regions of the cluster could not be classified because of overlaps in the spectra.

Four M stars between $V=12$ and $V=13$ —three of them already observed photometrically by Cuffey, and one of these (Z Sge) a previously known M star—were identified within $3'$ of the cluster center. A fainter star $4'$ from the center, also observed by Cuffey, shows *TiO*, as well as another star in the $V=12$ – 13 interval slightly farther out. The diameter of the cluster given by Hogg (1947) is $6.1'$, and an examination of the Palomar *Sky Atlas* indicates that this figure is by no means too large. Data for these stars are given in Table I, and an identification chart is given in Fig. 1. The spectral types of Table I are based on our criteria

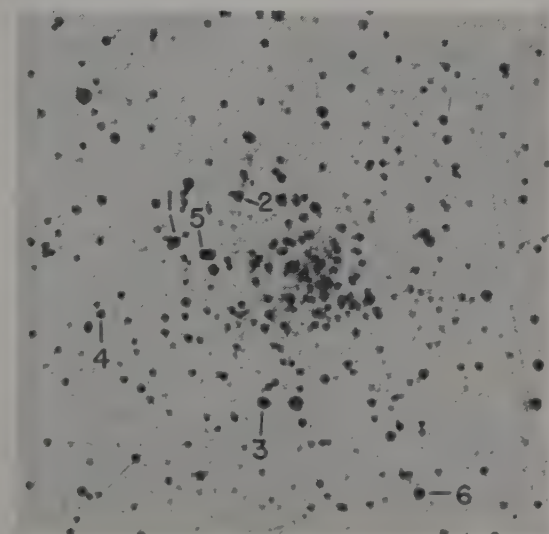


FIG. 1. NGC 6838. M stars are numbered as in Table I. North is at the top and east to the left; the field dimensions are $10' \times 10'$. Photovisual plate taken with the Burrell Schmidt telescope.

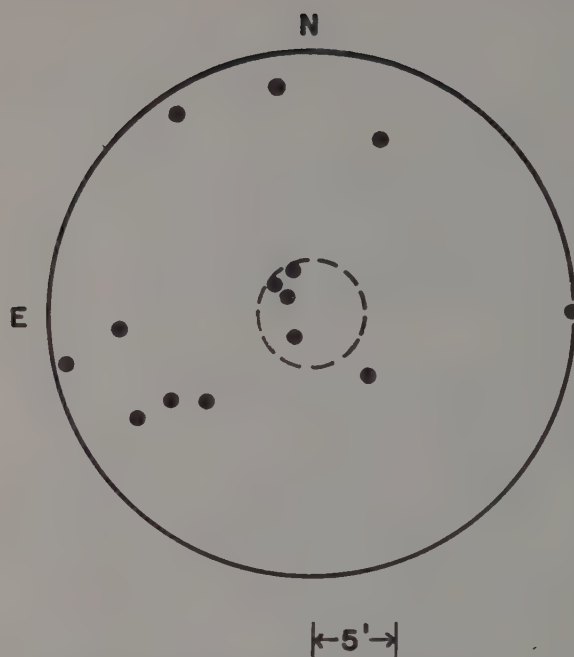


FIG. 2. M stars of type M4 and earlier, having $V \sim 12.0-13.0$, within $15'$ of NGC 6838. The dotted circle defines the cluster diameter given by Mrs. Hogg.

for normal stars of type M, as described in the references already cited.

DISCUSSION

It is unfortunately true that the M stars reported here cannot be assigned unambiguously to membership in the cluster. As has been stated by Cuffey (1959), his newer observations leave the giant branch of the color-magnitude diagram rather poorly defined. The basic difficulty is surely in part the great richness of the star field at $\mu = 57^\circ$, $\delta_{II} = -4^\circ 5'$ in which the cluster lies. However, to the extent that Cuffey's unpublished data for stars out to $3'$ from the cluster center do define a giant sequence, it is true that the M stars of Table I—except for No. 4—lie at the upper tip of the giant sequence. Two other stars within $3'$ of the center fall at the tip of the giant sequence and are not M stars, and the half-dozen remaining stars within $3'$ and as red as the bluest M star are too close to the cluster center to be classified on Case plates. The photometric data thus leave the problem in a rather unsettled state, while supporting the possibility of cluster membership.

Cuffey's colors for the M stars indicate that, if they are similar to the M giants in 47 Tucanae (Feast and Thackeray 1960), then NGC 6838 can be but little space-reddened. This seems implausible at such a low galactic latitude. However, it is difficult to check the point directly since the published color-magnitude diagrams (Cuffey 1943, Becker 1954) do not clearly define the main sequence; nor are any RR Lyrae stars

TABLE I. M stars near NGC 6838.*

No.	V	$P-V$	Type	Remarks
1	12.56	+1.40	M4	Z Sge
2	12.50	1.42	M0:	
3	12.45	1.53	M2	
4	13.73	1.94	M1	$4'$ from center
5	12.5	...	M3	
6	12.7	...	M3	$4.5'$ from center

* Photometric data for Nos. 1-4 are by Cuffey (unpublished).

known to be present. It has been emphasized by Cuffey (1943, 1959) that the cluster and its color-magnitude diagram do not conform well to the currently known properties of globular clusters, which further challenge distance estimates based on the known portion of the color-magnitude diagram. For that matter, the same point weakens the above criticism relating to the cluster reddening. In any event, Kinman (1958) has given an estimate of $13^{m}7 \pm 1$ for the true cluster distance modulus based on such quantities as size and integrated brightness. If the absolute V magnitude of the tip of the giant sequence is about -2 , which is perhaps reasonable from a comparison with 47 Tucanae, then at face value it appears that the cluster may indeed be little reddened—although the absence of galaxies from the field shows the total absorption in this direction to be large, as expected. Moreover, Becker (1954) fitted the giant branch of M3 observed by Sandage (1953) to NGC 6838 in a plausible fashion; the red end of the M3 giant branch has, according to the transformations given by Sandage, $P-V=1.5$, whence again the puzzling question of the reddening in NGC 6838 is to some extent seen to be independent of the problem of whether or not the M stars are cluster members. The colors of known OB stars in this general direction show fairly typical reddening, and it is not intended here to propose that the cluster reddening is in fact abnormal. It is perhaps not inappropriate to recall that NGC 6838 was once considered to be a galactic cluster (cf. Hogg 1947, 1958); this fact does not lessen the interest attaching to the question of the cluster membership of the M stars.

It is correct to say that the surface density of M stars in the relevant spectral and magnitude range is higher at the cluster than in any neighboring region. Nevertheless, a glance at Fig. 2 shows that the cluster is but poorly defined by the M stars alone.

NGC 6838 is rare among known globular or globular-like clusters in that its color-magnitude giant sequence, albeit poorly defined, exhibits M stars in close proximity in space direction to the cluster center. The question of their cluster membership is of considerable interest; even if the answer is negative, this will have some bearing upon future deliberations about any M stars that may be found in such faint globular clusters. A determination of radial velocities for these stars, even of low precision, might settle the matter. Two accordant

terminations of the cluster radial velocity (-80 m/sec) exist already (Mayall 1946, Kinman 1959).

ACKNOWLEDGMENT

I again acknowledge my gratitude to Dr. James Cuffey for furnishing me his unpublished photometric data and an identification chart for NGC 6838, without which this discussion would have been much less complete.

Note added in proof. The newly published paper of Kinman and Mayall (*Astron. J.* **65**, 581, 1960), which appeared while the present paper was in press, contains new evidence that the reddening of NGC 6838 is, in fact, small. Kron and Mayall give a value of 0.1 to 0.3 mag. for the cluster color excess in $P-V$.

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Problems in Meridian Astronomy

G. VAN HERK

U. S. Naval Observatory, Washington, D. C.*

AND

A. J. J. VAN WOERKOM

Electric Boat Company, New London, Connecticut

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The necessity for research in meridian astronomy is stressed, and several possibilities to increase the accuracy are proposed. It is emphasized that a meridian circle is a laboratory precision instrument that is used under trying circumstances. The shortcomings of modern meridian work are traced to several sources. Not much improvement in the final results has been made during the past century judged by differences in modern catalogues. Research in different directions is suggested to speed up the acquisition of improved proper motions.

1. COMPARISON OF MODERN CATALOGUES

IN discussing absolute proper motions, many authors blame the old observations for the apparent deficiencies. The arguments which are brought forth to discriminate against the older observations are lack of correction for variation of latitude prior to 1900, use of inferior-type clocks, use of the signal-key or the eye-and-ear method instead of the traveling wire micrometer, introduced by Repsold in 1896, and magnitude equations not eliminated. The improvements made in these particular branches are indeed tremendous. The final results of the observations would have improved materially if these deficiencies were the only or the main contributors to the final errors. They have not, however, altered the basic principles upon which a meridian circle operates, neither have they contributed to a better understanding of the reactions of such an instrument to its environment, nor have they helped to introduce the application of information theory.

The systematic differences among present-day star

catalogues are about as great as they were before the introduction of the improvements mentioned. To illustrate this, let us turn to Table I. Therein are tabulated the systematic differences between a pair of well-

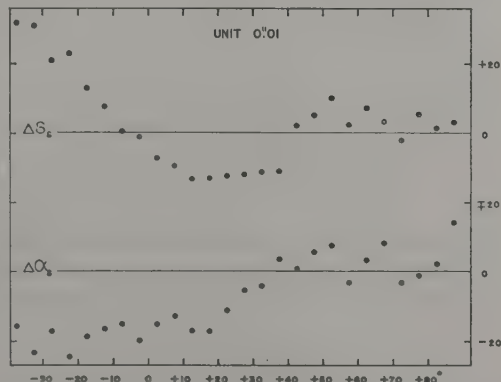


FIG. 1. Differences in α and δ for the 1471 stars common in the modern catalogues, U. S. Naval Obs. Publ. 15, 5 and 16, 1, averaged for intervals of 5° in declination.

* Now at Brorfelde Observatory, Denmark.

TABLE I. Smoothed differences 6-inch minus 9-inch ($1'' \times 10^{-2}$).

Dec.	$\Delta\alpha_\delta$	$\Delta\delta_\delta$	R.A.	$\Delta\alpha_\alpha$	$\Delta\alpha_\alpha$ suppl	$\Delta\delta_\alpha$
90°- 85°	+8	+2	0 ^b - 1 ^h	+2	+3	+2
85 80	+8	+3	1 2	+5	+8	+6
80 75	+7	+4	2 3	+7	+8	+7
75 70	+7	+5	3 4	+6	+6	+8
70 65	+6	+6	4 5	+4	+4	+5
65 60	+6	+7	5 6	+1	+1	+1
60 55	+5	+7	6 7	-2	-3	-2
55 50	+5	+8	7 8	-3	-4	-3
50 45	+4	+6	8 9	-2	-3	-5
45 40	+2	+2	9 10	0	-1	-5
40 35	-1	-5	10 11	+1	+2	-6
35 30	-3	-10	11 12	0	0	-7
30 25	-6	-12	12 13	-4	-4	-7
25 20	-10	-13	13 14	-8	-8	-6
20 15	-13	-13	14 15	-8	-9	-5
15 10	-15	-12	15 16	-7	-6	-2
10 5	-17	-10	16 17	-5	-3	0
5 0	-17	-7	17 18	-1	+2	+1
0 -5	-18	-3	18 19	+4	+8	+1
-5 -10	-18	+1	19 20	+5	+8	0
-10 -15	-19	+8	20 21	+3	+5	0
-15 -20	-19	+13	21 22	0	+2	0
-20 -25	-19	+18	22 23	-2	-1	0
-25 -30	-20	+25	23 24	0	0	0
-30 -35	-20	+30				
-35 -40	-20	+30				

observed and carefully discussed sets of positions for 1471 *General Catalogue* stars in common obtained with the nine-inch and six-inch transit circles at the U. S. Naval Observatory (*Publs. U. S. Naval Obs.* 15, part 5, 239; 16, part 1, 255, respectively). The $\Delta\alpha_\delta = 15\Delta\alpha^\circ \cos\delta$, and $\Delta\delta_\delta$ were derived by smoothing the values entered in Fig. 1. The $\Delta\alpha_\alpha$ and $\Delta\delta_\alpha$ are the averaged residuals after removing the former smoothed values. The column $\Delta\alpha_\alpha$ suppl resulted by leaving out stars north of 50° declination. These differences cannot be due to errors in the G.C. proper motions because the mean epochs of both catalogues were within 2.5 years of one another. The physical significance of terms depending on right ascension is rather obscure as it would seem that the practice of observing stars of the same right ascension over different parts of the year would tend to smooth out influences of several parameters depending on time of day and temperature.

The systematic differences in Table I are of the same order of magnitude as those found by comparing the appropriate columns published in *General Catalogue* Vol. 1 for Washington 60, Paris 60, and Greenwich 64. One cannot avoid concluding that, in this respect, modern star catalogues are not decidedly better than older catalogues. This, however, is not surprising because the use of the meridian circle has not basically changed in the meantime. Finally, the differences in α are of the same order as those in δ .

2. EXTENT OF IMPROVEMENT OF G.C. PROPER MOTIONS

The nature of these systematic differences has to be considered with the proposal that the *General Catalogue*

be improved by incorporating the meridian observations accumulated since its formation. The question arises as to whether the systematic differences at different epochs will balance out sufficiently to give an error-free system of motions. If one considers the large number of observations used to form the *General Catalogue*, it is questionable whether a great improvement can be expected in the systematic errors by introducing the modern observations. There is no doubt that the expected improvement in the internal mean errors in the proper motions will result. The increased time interval is the main contributing factor to the improvement. One should, therefore, hesitate to carry out the often-heard proposal to omit all observations performed before 1900. The internal improvement of the proper motions in declination has been estimated as follows from a sample comprising 8.5% of the stars. The comparison is made of the number of motions which are three or more times greater than their probable error with the expected number having the same ratio resulting from including an observation of weight 8 at epoch 1960. The frequency distribution of the proper motions in each subdivision was assumed to remain unchanged. The *General Catalogue* at present has 64% and 44% of its proper motions in declination in the above category in the northern and southern skies, respectively. The suggested improvement should yield 83% and 75%. Though the improvement would be substantial, the computations show that there will still be one star out of four or five which will not have the above-mentioned favorable ratio to its probable error. The result is favorable to those who use proper motions in large samples. However, it should be taken as a warning when small samples are involved. It is known, for instance, that for small groups of stars for which the proper motions were improved by adding the few new observations available, the average of the absolute values of the changes in the motions was equal to the average value of the absolute motions taken from the *General Catalogue*. No consideration was given to the effect of systematic errors. To test these, indirect approaches have to be used. It will be noted that Sollenberger (1945) found that the FK3 annual proper motions required a correction of $+0''.005$ to make them agree with the Washington PZT ($\delta = +39^\circ$) observations. If, by chance, the corrections required at $\delta = +51^\circ$ (Greenwich PZT) should be zero, then one half of the expansion found for the included zone would be explained (van Herk 1959).

3. LOCAL EFFECTS ON RIGHT ASCENSIONS

We may now ask why the systematic accuracy of meridian observations has not improved over those of a century ago. The thermal effects and local meteorological effects have by no means been considered completely. An example of the first was found in the effect of the heat flux from the observer on the flexure of the telescope (van Herk 1957). It can be added that the

TABLE II. Difference in longitude in milliseconds between neighboring U. S. Naval Observatory transit circles.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	267(4)	245(7)	285(8)	237(4)	243(3)	186(9)	176(10)	188(15)	176(12)	201(14)	221(15)	209(9)
2	180(14)	201(11)	175(12)	162(10)	170(12)	205(9)	174(9)	212(1)			208(17)	189(3)
3	188(17)	173(18)	170(12)	99(16)	90(7)	71(4)	34(15)	45(10)	42(8)	30(19)	53(22)	62(10)
4				150(9)	135(9)	113(13)	117(3)		153(14)	93(21)	124(17)	150(14)
5	128(8)	115(10)	89(15)	88(12)	102(13)	99(11)	112(4)	103(11)				

Building materials must have some influence, as will the accumulation of electronic equipment in the observing room. The influence of the surroundings has been treated in a semiquantitative way by Zimmermann (1931). To alleviate one evident source of trouble the wooden floor could be replaced to advantage by a grille of floor of a material of low heat capacity. The greater heat capacity and the improved ventilation might prove invaluable when the determination of the coefficient of flexure is considered. Also, since remote operation of the instrument has proved to be an advantage for the PZT, it should be used for meridian circles as well.

Local meteorological effects have often been treated in various publications. A general theory was summarized by Von Oppolzer (1891). Eddington (1913) demonstrated what effect small irregularities in the temperature distribution could have on the observed positions. The data necessary for an investigation of these local conditions can be obtained without great trouble with modern thermistors or thermocouples as is now planned at the U. S. Naval Observatory. The following example is suspected to have been caused by local meteorological conditions although a formal proof is missing for lack of data. The difference in longitude between the 6-inch and the 9-inch transit circles at the U. S. Naval Observatory is known to be $0^{\circ}.138$ from ordinary measurements. This value is compared with the results derived from transit observations. The ideal case in which the instruments used the same stars on the same nights was never reached, but the results to be discussed cannot be wholly attributed to this inhomogeneity. The observations used were never more than 0.2 day apart, and for 70% of them the interval was less than 0.1 day. Shortt clocks were used and their full daily rates were considered. The upper part of Table II gives the monthly averages with the number of determinations. The number of stars per determination is five or more.

The causes of the large deviations will never be reached. They show only that a meridian circle today cannot compete with a PZT or an astrolabe in determining time. The data in the lower part of Table II present a similar derivation of the difference in longitude between the 6-inch and the 7-inch instruments. The 7-inch is similar to and equipped with the same type of impersonal micrometer as the 6-inch and is located exactly on the site formerly occupied by the 6-inch. The instruments now use the same crystal

clocks. The latter differences are shown as a histogram in Fig. 2. They show less dispersion than the former. Nevertheless, they would yield the value $\pm 0^{\circ}.041$ for the probable error of one observation for each instrument. Although it is impossible to assess the dispersion in these differences to any particular meteorological cause, it is of the greatest importance to investigate all possible sources for the trouble. It is dangerous to argue that errors of this nature in the clock corrections will be automatically cancelled in the determination of right ascensions. One reason for this is that the clock stars are always confined to a certain declination belt; another, that the local troubles may depend on the zenith distance.

4. EFFECTS OF ERRORS IN COLLIMATION, LEVEL, AND AZIMUTH

An insufficient knowledge of the instrumental constants, collimation, level, and azimuth is a source of errors for the right ascensions. A change of the col-

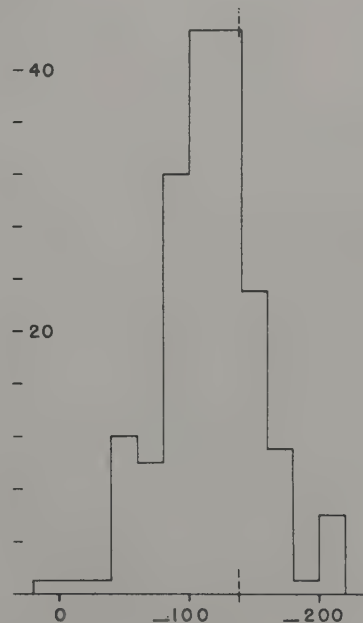


FIG. 2. Frequency distribution of the observed difference in longitude of the 6-inch and the 7-inch transit circles over the period of 1.5 years around 1959. Horizontal: $\Delta\lambda$ in milliseconds of time, the dashed line indicates the true $\Delta\lambda$.

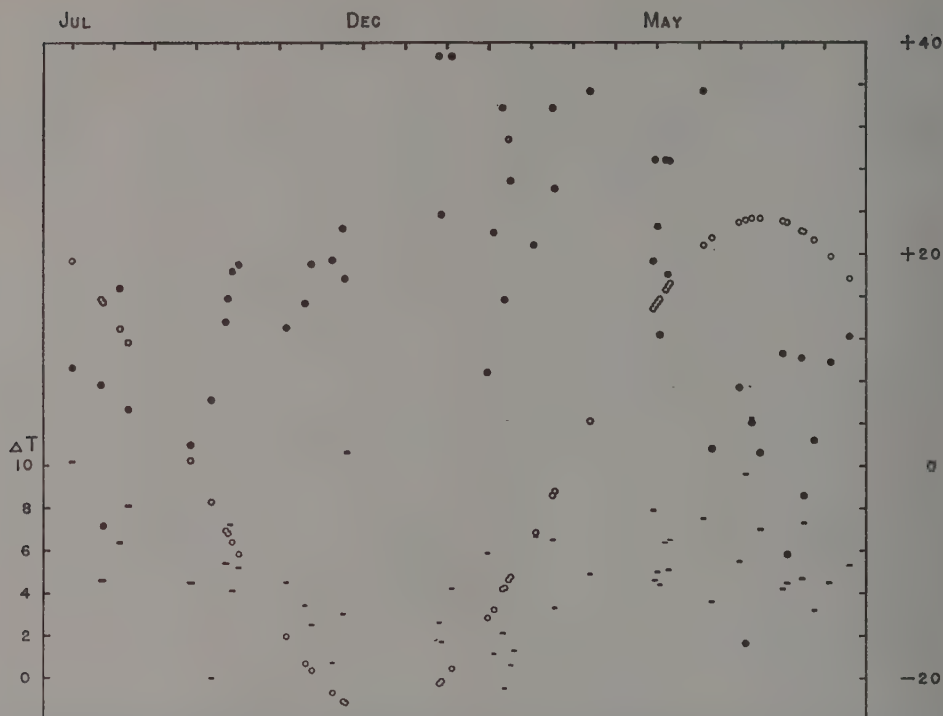


FIG. 3. From July 1956 to August 1957 for the 6-inch transit circle; open circles: declination of the sun; full dots: average δ for the day stars observed; dashes: differences in temperature ($^{\circ}\text{C}$) for the time when the sun was observed and the clock stars at the preceding or following nights.

limation with temperature is known to exist for many instruments. We can only emphasize the importance of shielding the telescope as much as possible against heat transfer. The level is very often determined in combination with the collimation. Any error in the latter quantity is introduced in both the level and the azimuth, which makes the time determination dependent on the declination. The latter will manifest itself as a $\Delta\alpha_3$ term in the right ascension. Random errors in the collimation will vary from night to night, but neglected temperature effects might be the cause of persistent $\Delta\alpha_3$ terms. The temperature coefficient for the azimuth is, for several instruments, surprisingly large. In Table III some temperature coefficients found in the literature are listed.

Morgan's method of deriving this coefficient yielded a smoothed value. The Edinburgh value is relative to the collimators. W. H. Finley's (1885) analysis for the Cape transit circle ends in the conclusion that temperature changes and rainfall cause changes in azimuth; it is not clear how much the first contributed and what the sign should be. An analysis of the azimuth of the 7-inch in Washington has, so far, revealed that the instrument acts like a slowly reacting thermometer and that one gains in using nonsmoothed data. The lag seems to be of the order of $6\frac{1}{2}$ days, but more data are needed before this quantity, as well as a possible second term which would have a much smaller time lag, will

be definitely determined. A very serious obstacle is that one usually does not know where the temperature should be measured. The reader is referred to Ellis's article in this respect.

The following example shows what errors may arise through an inadequate treatment of temperature effects. The data are taken from actual observations with the 6-inch in Washington, during the year beginning with July 1956. Figure 3 shows the declination of the sun and the average declination of the day stars for the days on which both were observed, and the difference between the air temperatures at the time of the sun and at the time of the night clock correction.

Without going into details, one can say that the "day correction" is based on a comparison of the right ascensions of the day stars derived from the night observations with those obtained during the day for these stars.

TABLE III. Temperature coefficients for the azimuth of transit circles.

Author	Instrument	$\frac{da}{dt}$ (sec per $^{\circ}\text{C}$)	lag
H. R. Morgan (1920)	9" Washington	+0.022	4 weeks
W. Ellis (1859)	Greenwich	+0.037	5 weeks
R. A. Sampson and E. A. Baker (1914)	Edinburgh	+0.014	small

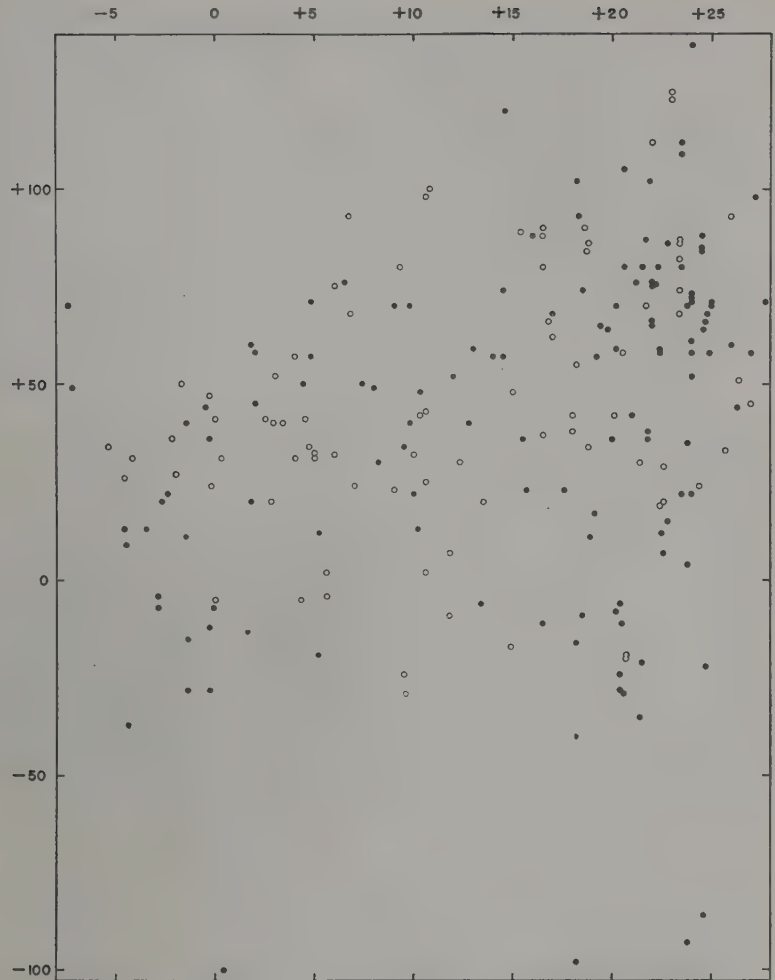


FIG. 4. Coefficients of horizontal flexure (in 0.01) for the 6-inch meridian transit circle against the surrounding air temperature (in °C). Horizontal: temperature. Full dots refer to clamp west, open circles to clamp east.

the meteorological conditions force the observers to make use of day stars which have the greatest possible difference in declination from the sun, then any error in the instrumental constants a , b , and c , due, for instance, to temperature effects, cannot be cancelled in the observations of the sun, since the coefficients A , B , and C by Mayer's formula differ appreciably for the sun and the day stars. Yearly periods in the sun's right ascension will then be introduced.

5. USE OF REFLECTION OBSERVATIONS

It will be evident that every possibility of obtaining independent determinations of the instrumental constants should be tried. In this respect, Danjon commented that part of the success of the astrolabe is to be attributed to the fact that the observations are used to define the pole of the small circle on which the stars are observed. To accomplish this, they have to be evenly distributed over this circle. The determination of the pole of the small circle on which stars are observed with

the meridian circle is very weak, because at the most only an arc of 120° is used to define the circle. Moreover, the uncertainty in the collimation enters the result. These objections can be met to a certain extent. Seen in the light of this geometrical explanation, it is surprising that reflection observations have only been used for the purpose of improving the determination of the flexure of the instrument, whereas they could help much to strengthen the determination of the pole of the small circle. In fact, they would more than double the weight because they would eliminate part of the systematic errors. The formula is

$$\alpha = T + \Delta T + aA + bB + cC,$$

where the δ used in computing A , B and C has to be taken as:

δ	in upper culmination, direct,
$180 - \delta$	in lower culmination, direct,
$180 - \delta + 2\varphi$	in upper culmination, reflected,
$\delta + 2\varphi$	in lower culmination, reflected.

TABLE IV. Time changes in horizontal flexure coefficients.

	0° to +10°C			+10° to +20°C			+20° to +30°C		
	rate	m.e.	r'	rate	m.e.	r'	rate	m.e.	r'
Clamp west	+0.035	±0.047	0.00	+0.080	±0.030	0.64	+0.115	±0.030	0.86
Clamp east	+0.048	±0.016	0.74	+0.076	±0.020	0.78	+0.023	±0.048	0.00

To make this suggestion work well, one has to make sure that the irregularities in temperature near the instrument do not spoil the observations. Looseness in the mounting of the objective and micrometer will cause changes in collimation as they also do in nadir observations.

6. LOCAL EFFECTS ON DECLINATIONS

Some of the difficulties encountered in determining declinations are shown in Fig. 4 where the horizontal flexure coefficients, as measured for the 6-inch transit circle in Washington are plotted against the temperature of the surrounding air. It is obvious that a relation between temperature and flexure is concealed by the large dispersion. These measurements extend over many years, and it is possible that a bivariate dependency exists. All material available was subdivided according to the months of the year as a substitute for a subdivision in temperature which was not readily available for all observations. Figure 5 shows the averages of the coefficient taken during the months December-March, April-July, and August-November, plotted against the year. Relative weights are indicated by differences in size of the

points. Open circles refer to measurements in clamping east, full dots to clamping west. These averages indicate as a preliminary result, a possible change with time. To investigate this somewhat further, only measurements made from 1951 on were used, since temperatures were available for these. The data were divided into three temperature intervals, 0° to +10°, +10° to +20°, and +20° to +30° (degrees C). Table IV gives the coefficients of an assumed linear time rate, in seconds of arc per year, followed by the mean error and the coefficient of simple linear correlation r' . Though the mean errors might suggest a linear time term (the average of all six positive values turns out to be +0.00 ±0.016, m.e.), the moderate-sized average value for r' shows that not sufficient significance can be attached to this result.

In fact, the results for the period 1959 to April 1960 are most responsible for the indication of a time rate. It could very well be that a small jump took place in 1958-1959 at an undefined time. The most likely explanation is that outside influences completely overwhelm the results.

This analysis stresses the need for a much more

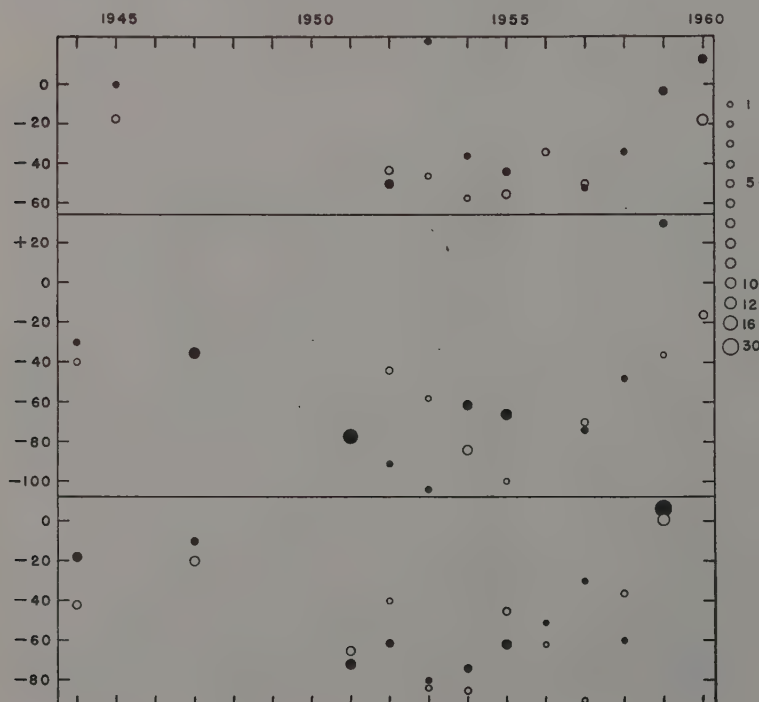


FIG. 5. Coefficients of horizontal flexure for the 6-inch transit circle (in 0.01, the signs are reversed with respect to those in Fig. 4). In the top, the average for December through March, in the middle, the average for April through July, and at the bottom the average for August through November are entered.

orough investigation. If the question is to be answered whether the flexure is a variable, one has to make certain that no outside influences interfere with the measurements. So far, the results obtained with the inch show a wild behavior similar to that of the 6-inch. If a new instrument were built, it would be advisable to investigate the flexure law by setting up more collimators at various zenith distances. To mount the collimators in the observing room, an arch supported by the two usual collimator piers is needed which would not interfere with the ordinary transit observations. These extra collimators could be placed in position whenever a flexure measurement is required. There is usually ample space to put the required collimators below the floor in a permanent position. The stability should not be an insurmountable problem as the measurements do not require much time. With such a device one could at least find out whether a single term of the Fourier development suffices. This scheme could yield reliable results only when no outside interference plays an important role and to minimize this, we refer again to the type of floor mentioned earlier.

Further, modern computing methods on the analysis of structural stress and flexures permit one to determine the astronomical flexure from the actual geometry of the telescope and the properties of the material of which it is constructed. It could very well be that this approach could yield better results than the measurements can do today (Timoshenko 1959).

7. APPLICATION OF INFORMATION THEORY

The meridian observer not only faces the difficulty of knowing what the actual position of his instrument is at the moment of the observation, but also what use he can make of the information his visual observation is giving him. He believes he is integrating with his eye. The eye may detect frequencies under 16 cps, but the process of integrating these lower frequencies is certainly very poor and will always be biased towards the immediate past. This will reduce the effective integration time and makes the operation rather a sampling over a short time. It is well known that the photographic plate is far superior to the human eye as an integrator and it is to be hoped that present attempts to use photography in transit work will eventually lead to catalogues based on this technique. It seems possible to make use of another integration process that will be more unbiased than the human eye, and which will separate noise effects from the real signals.

Figure 6 gives a block diagram of a system for driving a knife-edge prism that follows a star image through the field of the telescope. For detection of the light from either side of the prism the same photocell should be used. Utilizing two cells for this purpose would result in cumbersome calibration problems. Photocells like selected 1P21's combine high sensitivity with moderate size, and should for the latter reason be preferred to the

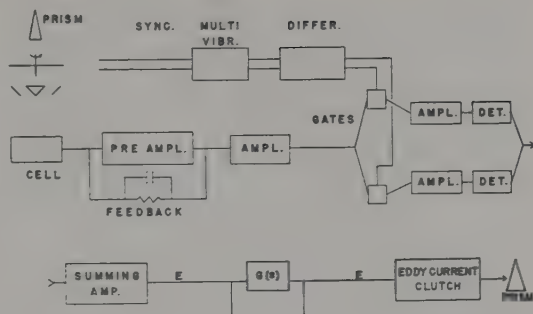


FIG. 6. Diagram showing a device to follow automatically a star image through the field of a telescope.

7265. The sensitivity will vary over the photocathode of the same tube by as much as 0.2 mag. It will be advisable not only to use the same tube for detection but also to use the same spot on the photocathode. This could be accomplished by the arrangement given in Fig. 6. The light, after reflection by the knife edge, passes a half-circle chopper and is reflected onto the same spot of the phototube. With an input load of 10^8 ohms the time constant of the phototube and preamplifier would be 1 msec. With negative feedback over the amplifier, this time constant would be drastically reduced. The easiest way to obtain negative feedback is to make the preamplifier a phase-inverting amplifier of fairly high gain, G . If R_1 represents the input resistance, then the effective input resistance will be $R_{in} = R_1 / (1 + G)$. Gains of 10^4 or 10^5 can be easily realized, thus reducing the time constant by an equivalent factor. By selecting the proper gain for the preamplifier almost any frequency response can be obtained. Chopper frequencies of 1 kc or higher have the advantage of simpler electronics as well as high stability.

After preamplification the signal passes through an amplifier and a set of gates. These gates can be synchronized to the chopper by means of an additional winding in the stator. The signals from this winding trigger either one or two bistable multivibrators. One could be used if dead time for the gates is not necessary. Cathode followers may be used for the gates, feeding the proper signals into a further amplification stage, the output of which is rectified and presented to a difference amplifier. The output of the difference amplifier is the error signal. Up to this point no integration of the signal has been introduced. Before the error signal is fed to the screw driving the knife edge, it can be fed through a filter which could take the form of an electronic integrator. Such an integrator consists of a very high gain dc amplifier with constant gain feedback. To avoid inertia in the screw driving the knife edge, two counter rotating motors with controlled slippage clutches driving the knife-edge screw should be used. Of the various clutches, the eddy-current clutch shows almost perfect characteristics. The existence of high torque at low output speed and almost perfect linearity of the torque

with the control signal makes this type of clutch suitable for speed control. One disadvantage of this clutch is the heat generation due to the necessary slippage. Part of this heat generation might be taken out by a heat sink using the reverse Peltier effect.

For simultaneous recording of right ascension and declination, a four-sided pyramid can be used instead of a knife-edge prism. Hardly any rearrangements will have to be made except that a four-phase chopper would have to be used as well as four gates. To insure that the light will always fall on the same spot of the photocathode, the photoelectric cell must also be moved in zenith distance as well.

With a 6-inch aperture the output of a selected IP21 phototube for a star of the eleventh magnitude will be approximately 2×10^{-9} amp, which is four times the dark current at $+25^\circ\text{C}$. Subtracting 1.5 mag. for absorption in the optics and losses at other reflecting surfaces, one finds that the limiting magnitude for the system will be 9.5 mag. The use of the chopper arrangement should reduce this value by another 1.5 mag.

A system like the one described above is superior to an electronic device which just records the passage of the star image past a cross wire. There, the random motion of the image in the focal plane makes it rather difficult to record the time of passage. Also, such a system cannot adequately deal with the effects of the lower frequency components in the random motion.

Integration of a signal is not in all cases the answer to proper filtering of signal from noise. It is known from theoretical work by Wiener, Kolmogoroff, and others (see Tsien 1954) that the statistical parameters that have to be known for the optimum filter are the frequency spectrum of the noise and the cross correlation between the noise and the signal. In order to determine these parameters, continuous recordings have to be available of the passage of a star through the field of the transit circle for right ascensions as well as continuous recordings of the micrometer readings for declinations. Let us first investigate how such continuous recordings can be obtained. As a first requirement no time lag can be allowed in either of these recordings. In terms of servo mechanisms this means that a closed-loop system will have to be used. By properly compensating a closed-loop servo, for which the mechanical and electrical frequency responses will have to be known, time lag can be indefinitely reduced (see Truxall 1958; Tsien 1954). For the continuous recording, the error-signal output from the summing amplifier can be used. It would be much better to put a digitizer on the lead screw of the knife-edge prism. Digitizing to 10 or 12 bits will be sufficient but will be dependent on the screw. The sampling speed should be equal to at least twice the highest frequency to be analyzed. For frequencies lower or equal to this so-called turnover frequency, no degradation of the measurements will be committed by this discrete sampling.

If it can be assumed that the instrument is stationary

in position during the complete run of the measurements, the signal can be represented by $x(i) = a + bi + ci^2$ where $x(i)$ is the position of the knife edge with respect to an arbitrary zero point. The first thing that should be done to keep the analysis simple is to determine preliminary values for a , b , and c . After removing the preliminary value for the signal, one can consider the remainder to be noise. For this noise the autocorrelation can be determined, the Fourier transform of which gives the frequency spectrum. From the little information available with respect to the spectrum of the motion, we can only expect that the noise spectrum will be pronounced at low frequencies, and we hope that it will be smooth above 10 cps. Such is the case with the power spectrum of the fluctuations in the extinction as was determined by Protheroe (1954) and several others. The two phenomena, motion of the image and fluctuation in brightness, are only weakly connected (Hosfeld 1954) and are caused by disturbances at two entirely different levels in the atmosphere. If, in analogy with the power spectrum for scintillation, the power spectrum for the motion of the image is smooth for frequencies higher than 10 cps, the complete sample can be run through a digital filter with a cutoff frequency of 10 cps to remove this part of the noise. The work of Gardiner *et al.* (1956) suggests that the assumption of a smooth frequency distribution for frequencies higher than around 15 cps may be true though their result is based only on the observations of one night. A digital filter consists of a set of numbers $a_1, \dots, a_k$ which are determined from a correlogram of a frequency spectrum that is flat to 10 cps and has a sharp cutoff. Then the filtered values x' are found from

$$x'_i = a_1 x_{i-(k-1)/2} + a_2 x_{i+1-(k-1)/2} + \dots + a_k x_{i+(k-1)/2}.$$

If the power spectrum should show considerable power in some discrete frequencies, say more than 30% of the total power, a more elaborate analysis will have to be done because the phase of these frequencies becomes important. The use of a smoothing filter then becomes questionable. No complete studies are available for fluctuations below 5 cps, however, work by Schlesinger (1916) and Land (1954) indicates that some rather predominant frequencies exist at 0.02 cps. The existence of these very low frequencies suggests that the time interval used for recording one transit should be taken as long as possible, preferably of the order of several minutes. This may require specially designed telescopes. In the article by Gardiner *et al.* the possibility of low frequencies with appreciable amplitudes is strongly suggested. After the removal of the higher frequency noise, the lower frequency noise can be analyzed.

As a by-product, the above-mentioned parameters, the noise spectrum, and the cross correlation of noise and signal can be obtained. If both are continuous with either frequency or time lag, an optimum filter can be designed (see Tsien 1954). If these parameters are not continuous, an optimum filter can be designed for the

tinuous portion. The end result has then to be fitted for the predominant frequencies. Once these frequencies and amplitude have been determined, these frequencies may be removed by a least-squares solution of the signal.

The advantages of the type of analysis sketched are obvious. First, bisecting errors can be avoided. Second, random systematic errors are avoided where predominant frequencies in the noise exist. Further, the measurements are not affected by the magnitude of the star.

Of course, full advantage of this method, which makes use of modern information theory, can be had only if the disturbing influences of systematic character are eliminated as much as possible from the neighborhood of the instrument.

SUMMARY

In Secs. 1 and 2 examples are given to deny the widespread idea that in modern meridian astronomy everything is above reproach. The systematic differences between modern catalogues suggest errors of the same order of magnitude as in catalogues based on old observations. It is suggested in Secs. 3 and 6 that part of the remaining uncertainties are caused by local circumstances. A discussion of the classical "constants" in Sec. 4 meant as a reminder how terms of the form $\Delta\alpha_3$ can be formed by a neglect of the local influences on these constants. In Sec. 5 it is suggested to improve on the determination of a and b by applying one of the principles on which the astrolabe is working. The last section, Sec. 7, is in our opinion the most important one as it deals with eliminating irregularities in the position of the stars due to disturbances in the atmosphere, local as well as distant. It is emphasized that an instrumental equipment which allows the application of modern information theory is bound to give great improvement over the ordinary type of observation with the eye.

Note added in proof. After the manuscript had been written, a paper by Erik Hög (1960) came to the atten-

tion of the authors in which a method is discussed for measuring transits photoelectrically. This method differs from the one proposed in the present paper in that it measures the time of transit over a grid consisting of a small number of lines instead of a continuous recording of the motion of the star in the field of the telescope. An advantage of Hög's method is the inexpensive way the digitizing of the information is accomplished by means of a pulsecounter which is sampled by a computer. The disadvantages of the method, which are more serious, are that it not only is affected by the random motion of the star image but also by random fluctuations in the extinction. The analyses given by Hög for these fluctuations in extinction is insufficient to obtain the errors introduced in the transit times.

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Comet Observations

G. VAN BIESBROECK

Yerkes Observatory, Williams Bay, Wisconsin

(Received December 12, 1960)

Observations are reported for 14 comets, made in 1957-60, mostly with the Yerkes 24-inch and McDonald 82-inch reflectors.

THE present observations are presented in the same form as the previous series (*Astron. J.* 63, 296, 1958) except that the positions are now uniformly given for the equinox of 1950. The great majority of the measures are obtained from plates taken at the Newtonian focus of the 24" reflector at the Yerkes Observatory. A smaller number were obtained at the prime focus of the 82" reflector of the McDonald Observatory. The pressure for time at that instrument is such that henceforth no further opportunity for such observation will be available. Only occasionally some plates were secured with the 10" Ross type lens which

the McDonald Observatory has on loan from the University of Pennsylvania.

Aside from the measures published here several other comets series are available but the publication is postponed until there is no further hope of extending period of observations.

ACKNOWLEDGMENT

Continued support of this work by a grant from the National Science Foundation is hereby gratefully acknowledged.

Comet 1956 c (Wirtanen)

UT ^a 1957	R.A.	Dec.	Exp. (Min.)	Instr.	Catal.
May 1.28444	15 ^h 11 ^m 13 ^s .78	-21°21'43".3	12	82" McD	Hyd
May 1.29844	15 11 15.23	-21 21 37.3	12	82 McD	Hyd
May 2.29471	15 10 52.91	-21 14 14.5	5	82 McD	Hyd
May 24.18860	15 2 37.82	-18 24 44.7	16	24 YK	Hyd
May 24.20145	15 2 37.52	-18 24 39.0	16	24 YK	Hyd
June 2.15360	14 59 56.98	-17 16 1.4	5	24 YK	Hyd
June 3.14891	14 59 30.44	-17 8 45.9	5	24 YK	Hyd
June 4.13065	14 59 14.52	-17 1 31.6	7	24 YK	Hyd
June 16.15731	14 56 38.24	-15 30 48.0	10	24 YK	Tac
June 17.16600	14 56 38.22	-15 30 42.4	11	24 YK	Tac
June 20.15787	14 56 18.48	-15 11 39.9	8	24 YK	Tac
June 20.16516	14 56 18.46	-15 11 36.9	9	24 YK	Tac
June 22.13892	14 56 9.00	-14 59 28.4	5	24 YK	Tac
June 27.13957	14 55 57.97	-14 30 13.7	6	24 YK	Tac
June 29.16278	14 55 59.07	-14 19 4.2	6	24 YK	Tac
July 16.13649	14 58 15.06	-13 0 51.5	10	24 YK	Tac
July 20.14249	14 59 20.25	-12 46 21.7	10	24 YK	Tac
July 23.12515	15 0 16.52	-12 36 31.7	10	24 YK	Tac
July 30.12493	15 2 54.97	-12 16 32.0	16	24 YK	Tac
Aug. 22.16458	15 15 37.37	-11 37 4.2	2	82 McD	Tac
Aug. 23.16035	15 16 17.93	-11 36 7.7	6	82 McD	Tac
Aug. 25.14635	15 17 40.51	-11 34 23.8	8	82 McD	Tac
Aug. 25.15538	15 17 40.54	-11 34 24.5	8	82 McD	Tac
Aug. 26.13519	15 18 22.60	-11 34 36.3	2	82 McD	Tac
Aug. 26.14491	15 18 22.98	-11 33 36.1	12	82 McD	Tac
Sept. 14.07367	15 33 27.25	-11 26 3.1	10	24 YK	Tac
Sept. 16.06046	15 35 12.40	-11 25 54.8	12	24 YK	Tac
Sept. 16.06949	15 35 13.07	-11 25 53.8	10	24 YK	Tac
Sept. 23.05725	15 31 36.01	-11 25 54.4	10	24 YK	Tac
Sept. 23.06432	15 41 36.40	-11 25 51.8	10	24 YK	Tac
Sept. 24.05978	15 42 56.00	-11 27 15.1	8	24 YK	Tac
Sept. 25.04897	15 43 29.00	-11 26 4.1	10	24 YK	Tac
Sept. 27.06630	15 45 24.99	-11 26 10.3	14	24 YK	Tac
1958					
Jan. 25.51637	17 59 57.53	-8 0 7.7	8	82 McD	SanF
Jan. 25.52406	17 59 58.01	-8 0 5.3	8	82 McD	SanF
Jan. 26.53024	18 1 0.89	-7 55 4.0	5	82 McD	SanF
Jan. 27.52771	18 2 2.94	-7 49 58.8	10	82 McD	SanF
Apr. 13.41641	18 57 1.15	+1 9 33.5	10	24 YK	Alg
Apr. 15.41117	18 57 38.99	+1 26 19.3	12	24 YK	Alg
May 20.36110	18 59 32.32	+6 6 37.5	20	24 YK	Tou
May 20.36110*	18 59 31.07	+6 6 23.9	14	24 YK	Tou

UT ^a 1958	R.A.	Dec.	Exp. (Min.)	Instr.	Catal.
May 20.37292	18 59 32.06	+ 6 6 43.6	20	24 YK	Tou
May 20.37292*	18 59 30.88	+ 6 6 26.4	13	24 YK	Tou
May 21.37001	18 59 21.94	+ 6 13 52.2	20	24 YK	Tou
May 21.37001*	18 59 20.73	+ 6 13 39.6	20	24 YK	Tou
May 23.36797	18 58 59.72	+ 6 27 58.2	22	24 YK	Tou
May 23.36797*	18 58 58.61	+ 6 27 44.6	22	24 YK	Tou
June 18.29444	18 50 51.15	+ 8 55 46.7	12	24 YK	Tou
June 18.29444*	18 50 50.05	+ 8 55 33.7	12	24 YK	Tou
Aug. 12.15764	18 31 12.46	+ 9 41 27.7	20	24 YK	Tou
Aug. 12.25852*	18 31 11.60	+ 9 41 20.2	10	82 McD	Tou
Aug. 12.25852	18 31 12.78	+ 9 41 34.8	10	82 McD	Tou
Aug. 13.29670*	18 31 1.44	+ 9 39 10.6	10	82 McD	Tou
Aug. 13.29670	18 31 2.35	+ 9 39 25.1	10	82 McD	Tou
Aug. 14.22708	18 30 52.08	+ 9 37 0.1	20	24 YK	Tou
Aug. 14.34784*	18 30 52.86	+ 9 37 9.1	10	82 McD	Tou
Aug. 14.34784	18 30 54.03	+ 9 37 23.9	10	82 McD	Tou
Aug. 15.27083*	18 30 44.09	+ 9 34 51.1	10	82 McD	Tou
Aug. 15.27083	18 30 46.93	+ 9 35 5.6	10	82 McD	Tou
Aug. 18.23681	18 30 22.88	+ 9 27 59.3	20	82 McD	Tou
Sept. 11.13047	18 31 15.88	+ 8 18 48.9	20	24 YK	Tou
Sept. 11.14610	18 31 15.98	+ 8 18 44.0	20	24 YK	Tou
Oct. 31.01654	18 52 48.77	+ 6 6 40.5	18	24 YK	Tou
Nov. 1.02005	18 53 28.07	+ 6 5 2.6	20	24 YK	Tou
Nov. 1.02005*	18 53 26.61	+ 6 4 52.4	20	24 YK	Tou
Nov. 11.03147	19 9 19.16	+ 5 50 0.3	20	24 YK	Tou
Nov. 11.04640	19 0 19.86	+ 5 49 59.9	20	24 YK	Tou
Nov. 29.00760	19 13 58.09	+ 5 44 8.5	20	24 YK	Tou
Nov. 30.01667	19 14 46.51	+ 5 44 18.9	20	24 YK	Tou
Dec. 2.01389	19 13 50.00	+ 5 46 20.1	20	24 YK	Tou

1959

Sept. 2.29648	20 39 2.47	+20 59 54.7	24	82 McD	Paris
Sept. 2.29648*	20 39 0.61	+20 59 43.8	24	82 McD	Paris
Sept. 3.16373	20 38 48.65	+20 56 54.8	24	82 McD	Paris
Sept. 3.16373*	20 38 47.04	+20 56 43.4	24	82 McD	Paris

Comet 1957 *d* (Mrkos)

1957					
Aug. 22.10627	12 16 5.40	+29 21 22.5	0.1	82 McD	Oxf
Sept. 1.07753	13 25 17.51	+17 54 13.5	0.5	24 YK	Par
Sept. 3.08905	13 35 21.18	+15 49 48.2	0.5	24 YK	Bord
Sept. 9.07080	14 0 21.81	+10 18 57.1	0.5	24 YK	Tou
Sept. 9.07195	14 0 21.94	+10 18 54.8	1	24 YK	Tou
Sept. 13.05902	14 14 0.26	+ 7 9 36.0	0.5	24 YK	Tou
Sept. 16.07913	14 23 9.12	+ 5 1 0.3	0.5	24 YK	Tou
Sept. 23.07325	14 41 28.30	+ 0 44 43.8	1	24 YK	Alg
Sept. 24.06742	14 43 48.97	+ 0 12 22.4	1	24 YK	Alg
Sept. 25.05765	14 46 6.09	- 0 18 54.4	1	24 YK	Alg
Sept. 27.05241	14 50 33.36	- 1 19 25.0	1	24 YK	Alg
Sept. 29.04014	14 54 48.59	- 2 16 29.9	1	24 YK	S. Fern
Sept. 30.05123	14 56 54.74	- 2 44 20.6	1	24 YK	S. Fern
Oct. 1.05058	14 58 56.89	- 3 11 9.4	1	24 YK	S. Fern
Oct. 2.04119	15 0 56.07	- 3 37 6.1	1	24 YK	S. Fern
Oct. 2.04571	15 0 56.50	- 3 37 13.4	2	24 YK	S. Fern
Oct. 3.04236	15 2 54.22	- 4 2 37.2	1	24 YK	S. Fern
Oct. 4.03956	15 4 49.91	- 4 27 25.0	1	24 YK	S. Fern
Oct. 5.03792	15 6 43.93	- 4 51 36.2	2	24 YK	S. Fern

1958

Jan. 25.49999	17 17 13.43	-24 2 2.5	5	82 McD	Cord
Jan. 26.51869	17 17 49.73	-24 7 9.3	6	82 McD	Cord
Jan. 27.51098	17 18 33.78	-24 12 6.8	10	82 McD	Cord

Comet 1957 *g* (Periodic Harrington 1952 II)

1958					
Aug. 22.46591	7 25 52.73	+18 54 25.1	10	82 McD	Paris
Aug. 22.47216	7 25 53.17	+18 54 19.7	6	82 McD	Paris
Sept. 12.41525	8 22 34.54	+13 17 26.4	10	24 YK	Bord
Sept. 12.42220	8 22 35.84	+13 17 20.8	10	24 YK	Bord

Comet 1958 *a* (Burnham)

1958					
Feb. 27.06825	5 56 20.21	+11 53 10.7	0.5	24 YK	Bord
Mar. 7.04433	6 6 42.67	+14 50 36.8	1	24 YK	Bord
Mar. 10.07715	6 11 42.90	+15 58 45.4	0.5	24 YK	Bord

UT ^a 1958	R.A.	Dec.	Exp. (Min.)	Instr.	Catal.
Mar. 12.06409	6 15 19.00	+16 43 22.1	0.5	24 YK	Bord
Mar. 13.05167	6 17 11.94	+17 5 26.5	1	24 YK	Bord
Apr. 8.11218	7 30 5.00	+25 46 24.8	1	24 YK	Oxf
Apr. 12.08625	7 44 52.24	+26 44 43.7	1	24 YK	Oxf
Apr. 13.06992	7 48 39.75	+26 57 51.1	1	24 YK	Oxf
Apr. 14.08935	7 52 38.33	+27 10 51.0	1	24 YK	Oxf
Apr. 17.09416	8 4 38.80	+27 45 30.1	1	24 YK	Oxf
Apr. 20.11295	8 17 6.42	+28 14 30.4	1	24 YK	Oxf
May 6.11690	9 27 11.42	+28 59 52.3	1	24 YK	Oxf
May 7.12723	9 31 41.42	+28 56 26.2	1	24 YK	Oxf
May 10.10741	9 44 55.88	+28 41 56.6	1	24 YK	Oxf
May 19.12686	10 24 6.82	+27 21 59.0	1	24 YK	Oxf
May 20.13717	10 28 22.66	+27 9 56.1	1	24 YK	Oxf
May 24.16107	10 45 22.04	+26 16 40.3	1	24 YK	Oxf
June 7.16442	11 38 27.98	+22 20 29.0	1	24 YK	Paris
June 7.16616	11 38 28.44	+22 20 27.8	2	24 YK	Paris
June 20.13645	12 21 17.26	+18 2 54.6	2	24 YK	Paris
June 21.16395	12 24 25.67	+17 41 54.7	4	24 YK	Paris
July 21.13859	13 43 7.70	+7 53 44.0	8	24 YK	Tou
Aug. 12.12820	14 30 6.45	+1 51 31.6	8	82 McD	Alg
Aug. 12.14226	14 30 8.04	+1 51 19.4	6	82 McD	Alg
Aug. 14.18221	14 34 12.14	+1 21 20.0	8	82 McD	Alg
Aug. 15.14483	14 36 6.28	+1 7 24.6	8	82 McD	Alg
Aug. 18.14173	14 41 58.84	+0 24 53.6	10	82 McD	Alg
Aug. 20.16140	14 45 53.90	- 0 3 1.0	8	82 McD	Alg
Aug. 20.16693	14 45 54.46	- 0 3 6.0	8	82 McD	Alg

Comet 1958 *d* (Periodic Kopff 1906 IV)

1958					
Aug. 12.40892	2 38 54.64	+ 9 51 52.5	10	82 McD	Tou
Aug. 13.40023	2 39 25.78	+ 9 52 1.8	20	82 McD	Tou
Aug. 15.34229	2 40 23.55	+ 9 51 58.8	16	82 McD	Tou
Aug. 16.40724	2 40 51.16	+ 9 51 41.0	20	82 McD	Tou
Aug. 17.35773	2 41 15.26	+ 9 51 25.2	16	82 McD	Tou

Comet 1958 *e* (Burnham-Slaughter)

1958					
Sept. 12.15133	21 11 2.10	+10 55 22.9	5	24 YK	Tou
Sept. 13.07325	21 9 30.78	+11 1 19.8	6	24 YK	Tou
Sept. 15.11240	21 6 10.84	+11 14 3.3	6	24 YK	Tou
Sept. 19.08316	20 59 54.07	+11 37 3.1	6	24 YK	Tou
Oct. 29.03438	20 22 1.21	+14 31 8.7	5	24 YK	Tou
Oct. 30.01788	20 21 45.57	+14 35 35.7	10	24 YK	Bord
Oct. 30.02413	20 21 45.25	+14 35 38.4	5	24 YK	Bord
Nov. 1.00512	20 21 18.29	+14 44 53.5	6	24 YK	Bord
Nov. 11.07111	20 20 53.24	+15 37 42.8	5	24 YK	Bord
Nov. 19.05034	20 22 39.18	+16 28 16.6	3	24 YK	Bord
Nov. 21.00347	20 23 20.75	+16 42 16.9	5	24 YK	Bord
Nov. 27.01188	20 26 6.82	+17 28 16.3	5	24 YK	Bord
Nov. 27.01639	20 26 6.89	+17 28 20.5	3	24 YK	Paris
Nov. 28.99331	20 27 23.04	+17 44 54.0	3	24 YK	Paris
Dec. 2.02986	20 29 5.29	+18 11 36.8	5	24 YK	Paris
Dec. 5.99779	20 31 51.91	+18 49 10.5	5	24 YK	Paris
Dec. 9.05877	20 34 16.80	+19 20 12.6	4	24 YK	Paris
Dec. 10.00538	20 35 3.80	+19 30 12.4	5	24 YK	Paris
Dec. 11.99966	20 36 47.16	+19 51 46.2	5	24 YK	Paris
Dec. 20.99956	20 47 2.33	+21 56 57.2	4	24 YK	Paris
Dec. 25.99030	20 54 18.26	+22 50 25.2	4	24 YK	Paris
Dec. 27.99080	20 55 40.01	+23 27 17.3	3	24 YK	Paris
1959					
Jan. 5.01112	21 4 31.06	+25 24 0.5	3	24 YK	Oxf
Jan. 6.01948	21 5 57.91	+25 41 4.6	6	24 YK	Oxf
Jan. 10.01681	21 4 58.85	+26 51 29.7	4	24 YK	Oxf
Jan. 28.04127	21 44 23.10	+33 3 56.7	3	24 YK	Oxf
Jan. 31.04528	21 51 0.42	+34 14 49.3	3	24 YK	AGK ₂
Feb. 2.94113	21 55 34.53	+35 3 11.8	3	24 YK	AGK ₂
Feb. 7.01890	22 7 22.14	+37 8 11.6	3	24 YK	Hyd
Feb. 28.08615	23 12 48.47	+46 48 39.9	8	82 McD	Hels
Mar. 3.08550	23 27 7.93	+48 29 43.1	6	82 McD	Cat
Mar. 11.05793	0 0 47.52	+51 49 54.4	10	24 YK	Cat
Mar. 12.06391	0 5 52.38	+51 50 48.4	10	24 YK	Cat

UT ^a 1959	R.A.	Dec.	Exp. (Min.)	Instr.	Catal.
Mar. 13.07576	0 10 58.92	+53 8 17.0	6	24 YK	Cat
Apr. 4.18964	2 30 49.15	+58 46 15.1	10	24 YK	Vat
Apr. 5.12300	2 37 31.01	+58 50 24.8	8	24 YK	Vat
Apr. 6.12896	2 44 45.17	+58 53 42.2	5	24 YK	Vat
May 2.13378	5 31 27.11	+54 9 13.9	6	24 YK	Cat
May 6.12571	5 50 59.96	+45 37 37.3	6	24 YK	Cat
May 12.11358	6 17 18.30	+50 17 18.8	5	24 YK	Cat
May 25.15484	7 4 10.49	+44 56 8.5	6	24 YK	Hels
June 2.12500	7 27 27.26	+41 40 34.5	9	24 YK	Hels
June 3.15007	7 30 12.60	+41 15 52.8	12	24 YK	Hels
June 4.13442	7 32 51.58	+40 52 13.6	12	24 YK	Hels

Comet 1959 *b* (Periodic Giacobini-Zinner)

1959					
July 2.15057	16 59 10.29	+32 32 10.0	20	24 YK	Oxf
July 2.16515	16 59 8.71	+32 32 19.7	20	24 YK	Oxf
July 3.10133	16 57 41.14	+32 39 57.2	20	24 YK	Oxf
July 3.11696	16 57 39.72	+32 40 1.8	20	24 YK	Oxf
July 4.13635	16 56 12.36	+32 47 5.7	20	24 YK	Oxf
July 7.13944	16 51 47.54	+33 5 11.9	20	24 YK	AGK ₂
July 29.13913	16 26 46.88	+32 47 17.4	10	24 YK	Oxf
Aug. 1.12137	16 24 13.19	+32 26 33.0	10	24 YK	Oxf
Aug. 2.13243	16 23 36.82	+32 18 41.9	12	24 YK	Oxf
Aug. 5.14786	16 22 2.88	+31 52 44.0	10	24 YK	Oxf
Sept. 2.15038	16 28 28.96	+25 20 13.1	2	82 McD	Oxf
Sept. 5.20274	16 31 31.79	+24 21 34.2	10	10 McD	Paris
Sept. 5.21003	16 31 32.30	+24 21 26.8	10	10 McD	Paris
Sept. 22.08550	16 56 42.91	+17 36 13.0	10	24 YK	Paris
Sept. 22.09276	16 56 43.72	+17 36 0.4	4	24 YK	Paris
Sept. 30.03328	17 13 51.41	+13 15 37.3	3	24 YK	Bord
Oct. 10.02811	17 44 24.91	+5 58 30.3	2	24 YK	Tou
Oct. 29.04160	19 2 36.19	-17 23 13.1	1	24 YK	Hyd
Nov. 9.00032	20 21 30.89	-35 45 53.2	1	24 YK	Perth

1960

Jan. 17.09597	3 49 10.80	-33 10 52.0	8	24 YK	Cord
Jan. 23.05935	4 2 8.78	-30 25 16.4	8	24 YK	Cord
Feb. 15.09971	4 46 33.88	-20 49 0.0	6	24 YK	Hyd
Feb. 20.06767	4 55 30.77	-19 0 23.6	10	24 YK	Hyd
Mar. 1.11863	5 13 59.55	-15 45 32.9	10	24 YK	Tou
Mar. 19.09806	5 44 22.34	-10 40 39.0	8	82 McD	Tou
Mar. 20.08987	5 46 5.00	-10 26 16.6	5	82 McD	Tou

Comet 1959 *c* (Periodic Arend)

1959					
Nov. 29.21270	7 7 47.21	+60 13 55.0	10	24 YK	Vat
Nov. 30.18978	7 7 17.62	+60 21 40.8	11	24 YK	Vat

Comet 1959 *e* (Alcock)

1959					
Sept. 1.11081	16 25 21.33	+28 20 21.9	5	10 McD	Oxf
Sept. 1.12227	16 25 24.89	+28 19 36.1	5	10 McD	Oxf
Sept. 1.22223	16 25 55.12	+28 12 59.2	6	82 McD	Oxf
Sept. 2.16374	16 30 45.97	+27 10 14.3	2	82 McD	Oxf
Sept. 3.14505	16 35 49.99	+26 2 58.8	2	82 McD	Oxf
Sept. 5.20274	16 46 29.40	+23 36 25.1	5	10 McD	Paris
Sept. 5.21003	16 46 32.13	+23 35 49.8	5	10 McD	Paris
Sept. 22.06678	18 13 24.07	+1 9 5.4	16	24 YK	Alger
Oct. 21.02026	20 19 23.93	-24 14 44.6	24	24 YK	Cord
Oct. 21.03866	20 19 28.30	-24 15 20.4	24	24 YK	Cord

Comet 1959 *f* (Alcock)

1959					
Sept. 1.45910	8 31 26.50	+14 13 7.4	3	82 McD	Bord
Sept. 2.47378	8 41 42.47	+12 34 32.6	2	82 McD	Bord
Sept. 3.47624	8 52 20.42	+10 51 56.9	2	82 McD	Bord
Sept. 4.47387	9 3 21.75	+9 5 24.1	1	82 McD	Tou
Sept. 5.47381	9 14 55.86	+7 14 33.7	2	10 McD	Tou
Sept. 5.47664	9 14 57.51	+7 14 16.3	2	10 McD	Tou

UT*	R.A.	Dec.	Exp. (Min.)	Instr.	Catal.
Comet 1960 a (Burnham)					
1960					
Feb. 19.05140	3 48 18.31	+24 59 51.0	10	24 YK	Oxf
Feb. 20.05619	3 48 55.03	+25 15 59.7	10	24 YK	Oxf
Mar. 1.06970	3 56 1.82	+27 42 25.8	16	24 YK	Oxf
Mar. 19.11333	4 12 29.24	+31 14 57.5	10	82 McD	Oxf
Mar. 20.13222	4 13 31.37	+31 25 27.9	10	82 McD	Oxf
Mar. 21.15978	4 14 32.19	+31 35 31.1	10	82 McD	Oxf
Comet 1960 b (Wild)					
1960					
Apr. 22.18007	10 34 45.78	+ 6 51 20.7	10	24 YK	Tou
Apr. 22.18736	10 34 45.92	+ 6 51 13.0	10	24 YK	Tou
Apr. 23.11558	10 35 8.30	+ 6 35 2.5	20	24 YK	Tou
Apr. 23.13016	10 35 8.65	+ 6 34 46.4	20	24 YK	Tou
Apr. 25.11780	10 35 56.32	+ 6 0 14.6	16	24 YK	Tou
Apr. 27.12572	10 36 51.60	+ 5 25 53.9	10	24 YK	Tou
Comet 1942 VII (Periodic Oterma)					
1958					
Apr. 8.10112	8 19 3.46	+18 20 38.0	16	24 YK	Paris
Apr. 12.10153	8 20 45.13	+18 19 26.1	20	24 YK	Paris
Apr. 13.08484	8 21 12.72	+18 18 59.6	20	24 YK	Paris
Apr. 14.10255	8 21 42.18	+18 18 24.3	20	24 YK	Paris
Apr. 17.11117	8 23 13.88	+18 16 20.4	21	24 YK	Paris
1959					
Feb. 17.42425	13 38 19.50	- 7 7 3.5	10	82 McD	S. Fern
Feb. 17.43293	13 38 19.59	- 7 7 1.8	10	82 McD	S. Fern
Apr. 6.14530	13 21 27.08	- 4 25 21.4	16	24 YK	S. Fern
Apr. 6.15708	13 21 26.59	- 4 25 15.8	16	24 YK	S. Fern
May 2.15080	13 6 15.53	- 2 41 30.8	16	24 YK	S. Fern
June 2.14303	12 57 58.29	- 1 59 6.0	18	24 YK	Alger
June 3.13331	12 57 57.99	- 1 59 37.5	16	24 YK	Alger
Comet 1925 II (Periodic Schwassmann-Wachmann 1)					
1958					
Aug. 12.39123	23 50 44.14	+ 5 21 32.1	10	82 McD	Tou
Aug. 14.34167	23 50 10.74	+ 5 21 2.4	10	24 YK	Tou
Aug. 14.35903	23 50 10.54	+ 5 21 2.5	30	24 YK	Tou
Aug. 15.41481	23 49 51.32	+ 5 20 36.2	10	82 McD	Tou
Aug. 16.44749	23 49 32.22	+ 5 20 8.9	10	82 McD	Tou
Aug. 23.36111	23 47 11.51	+ 5 15 18.5	10	24 YK	Tou
Sept. 12.18883	23 38 56.48	+ 4 46 9.8	20	24 YK	Tou
Sept. 22.36801	23 34 20.20	+ 4 25 6.3	15	24 YK	Tou
Oct. 31.03311	23 20 53.81	+ 3 5 7.2	10	24 YK	Alger
Nov. 1.07630	23 20 42.10	+ 3 3 33.1	10	24 YK	Alger
Nov. 12.13532	23 19 21.86	+ 2 50 47.9	20	24 YK	Alger
Nov. 29.02913	23 19 56.46	+ 2 45 41.6	10	24 YK	Alger
Dec. 2.04028	23 20 22.03	+ 2 46 42.7	10	24 YK	Alger
Dec. 6.00853	23 21 4.84	+ 2 48 56.9	10	24 YK	Alger
Dec. 9.07306	23 21 44.75	+ 2 51 26.9	10	24 YK	Alger
Dec. 12.01164	23 22 28.15	+ 2 54 32.1	10	24 YK	Alger
1959					
Jan. 10.02826	23 33 50.15	+ 3 52 51.3	10	24 YK	Alger
July 3.34971	1 28 29.36	+17 27 22.0	20	24 YK	Bord
July 10.35271	1 31 16.89	+17 54 35.6	20	24 YK	Par
Sept. 1.33485	1 35 9.04	+19 54 52.1	10	82 McD	Par
Sept. 2.33658	1 34 56.32	+19 55 29.3	10	82 McD	Par
Sept. 3.28483	1 34 43.71	+19 55 58.1	10	82 McD	Par
Sept. 8.40070	1 33 27.84	+19 57 38.5	10	82 McD	Par
Oct. 29.09267	1 12 28.12	+18 42 50.3	10	24 YK	Par
Nov. 18.03034	1 5 7.17	+17 54 46.2	10	24 YK	Par
Nov. 29.18943	1 2 26.10	+17 23 15.9	10	24 YK	Bord
Dec. 30.03579	1 2 1.59	+16 40 33.4	10	24 YK	Bord

* The observations marked * refer to the second nucleus.

REMARKS

et 1956 c (Wirtanen)

- 1 Round diffuse coma 15" in diameter with well-defined nucleus. Tail 4' in position angle 255°. Total 13 mag. There is a second nucleus at 8" from the main nucleus, 2.5 mag, fainter in position angle 204°. Same appearance but second nucleus too difficult on smaller scale plate.
- 2-4 Total 12 mag.
- 20 Total 12 mag. Faint tail 3' in 260°. The companion nucleus only vaguely suspected on these small scale plates.
- 23 Second nucleus in 329° at 8".7 from the main one.
- 25 Second nucleus in 330° at 8".6 from the main one.
- 26 Second nucleus in 331° at 8".65 from the main one.

- 25-27 Nearly round coma 25" in diameter with a well-defined nucleus 16 mag. Only a vague suspicion of a second nucleus at 15" in 215° about 18 mag.
- 13-15 A short fan emanates from the nucleus in 60° ending at a round envelope curving back into a very faint tail in 260°. Total 16.5 mag. The second nucleus, at 20" from the nucleus in 240°, appears as a round spot 5" in diameter of 18 mag.
- 20-21 Sharp nucleus. Fan-shaped coma in first quadrant. Fuzzy second nucleus 18 mag. Total 15.5 mag.
- 18 Both nuclei well defined, 15.5 and 17.5 mag.
- 12-15 Both nuclei well defined. The coma extends in a broad fan in the first quadrant 35" from the main nucleus. Mags. 16 and 18.
- 11 Only the main nucleus is visible. Total 17 mag.
- 31 Diffuse nucleus and coma. 18 mag.
- 1 Very diffuse nucleus. Coma hardly visible. Mags. 17.5 and 18.5.
- 29-30 Round diffuse spot. 18.5 mag.
- 2 Image very faint at low altitude.
- 2-3 Both components appear as round comas, centrally condensed, of 10 and 6" diameter and 18 and 19.5 mag., respectively.

et 1957 d (Mrkos)

- 13-14 On a 10-min. exposure with the 10" Cook lens the bright head is surrounded by a spherical envelope nearly 10' in diameter. The tail shows a complex structure consisting of several straight filaments in position angle 30° to 35° and a broad curved branch in 10° to 25° position angle. The east side is sharply defined while the opposite side melts away westward.
- 15 Narrow bundle of filaments in the tail, recorded over a length of 5° in position angle 40°, overlaid with a shorter broad branch curving westward. Beside there is a faint filament 1° long toward 320° position angle.
- 16-17 The straight branch, about 10° long to the naked eye, consists of a dozen narrow filaments some of which have a wavy structure. The curved branch has diminished in brightness.
- 18 A bright straight filament in 49° position angle stands apart from the main bundle of filaments which is pointing toward 45°. The diffuse branch is very faint.
- 22 Even in this 4-sec exposure the sharp nucleus is hardly visible in the bright coma. A half-min. exposure brings out a bundle of wavy thin filaments streaming out in 245° imbedded in a paraboloid envelope.
- 23 A 20-min. exposure with a wide-angle camera shows that the tail splits at about 2° from the nucleus: one branch goes out straight over 6° in 245° while the other curves northward; the southern edge of this branch is well defined but the northern one is diffuse making the tail more than 2° wide towards its end some 7° from the nucleus. Beyond 6° the first branch splits in turn into a diffuse stub con-

Sept. 3

Sept. 16

Sept. 24

Sept. 30

Oct. 1-5

1958

Jan. 25-27

Comet 1957 g (Periodic Harrington 1952 II)

1958

Aug. 22

Sept. 12

Comet 1958 a (Burnham)

1958

Feb. 27

Mar. 10

Mar. 12

Mar. 13

Apr. 8

Apr. 12

Apr. 13

Apr. 17

May 6

May 7

May 10

May 19

May 20

June 7

June 20

July 21

Aug. 12

Aug. 14

Aug. 15

Aug. 18

Aug. 20

Comet 1958 d (Periodic Kopff 1906 IV)

1958

Aug. 12-17

Comet 1958 e (Burnham-Slaughter)

1958

Sept. 12-19

Oct. 30

Nov. 1

Nov. 19-27

Dec. 2

Dec. 5

Dec. 10

Dec. 20

Dec. 25

Dec. 27

tinuing 2° in 250° and a ragged fainter branch continuing in 230° as far as 16" from the nucleus.

Well-defined nucleus in a round coma 1.5 in diameter surrounded by a paraboloid envelope curving back into a bundle of streamers. The brighter central streamer is seen in 85° over a length of only 1° in a hazy sky.

Same appearance. BD+6°2895-5- ϵ -5-BD+5°2886. Hence 5.6 mag.

BD-0°2886-1- ϵ -2-BD+0°3253. Hence 6.1 mag.

BD-2°2933= ϵ . Hence 6.5 mag.

At low altitude the broad diffuse tail in the first quadrant is very faint. Well-defined nucleus.

Round coma 25" in diameter centrally condensed in a 5" nucleus. 15.5 mag.

Fuzzy round nucleus with a very faint narrow tail 1' in 280°. Total 17 mag.

17 mag.

Faint diffuse spot on plate fogged by nearby moon. Coma 1' in diameter with faint extension toward 100°. Small but not stellar nucleus of 12 mag. Total 10.2 mag.

A 20-min. exposure shows a slender faint tail 10' long in 85°.

ϵ -2-BD+17°1485. Hence 8.6 mag.

BD+26°1585-2- ϵ =BD+26°1590. Hence 8.9 mag.

BD+27°1485-2- ϵ -4-BD+26°1658. Hence 8.9 mag.

ϵ -2-BD+27°1485. Hence 8.4 mag.

BD+28°1568-1- ϵ . Hence 9.5 mag.

BD+29°1905-2- ϵ . Hence 9.0 mag.

Much brighter. ϵ -1-BD+28°1772. Hence 8.2 mag.

Well-defined nucleus surrounded by a coma 4' in diameter. Faint tail 8' in 117°.

BD+28°1810-1- ϵ -1-BD+29°1951. Hence 10.0 mag.

BD+28°1882-2- ϵ -3-BD+28°1892. Hence 9.9 mag.

BD+28°1894-2- ϵ -3-BD+27°1900. Hence 10.1 mag.

10 mag.

Well-condensed round nucleus surrounded by a faint coma extending mostly in 90°. ϵ -1-BD+18°2604. Hence 9.4 mag.

Centrally condensed round coma. 15 mag.

Nucleus 3" in diameter in a faint coma extending mostly in 110°. 16 mag.

Image faint through haze.

16.5 mag.

16.5 mag.

17 mag.

Round coma 10" in diameter with little central condensation. 18.5 mag.

Well-defined central condensation in a dissymmetrical coma extending to 30" into a fan-shaped tail. Total 14.5 mag.

Centrally condensed round coma 4" in diameter. Faint fan-shaped tail centered in 120° extending to 30°. Total 15 mag.

Some appearance and brightness except that the fan-shaped tail is centered in 80°.

Faint and difficult in moonlight.

The tail is centered towards 50°.

Nucleus very eccentrically situated in a coma extending 30" in a broad fan between 0° and 120°.

Nucleus 8" in diameter. Faint coma extending mostly in 70°.

Diffuse round coma. Faint on plate fogged by moonlight.

Diffuse round coma 14 mag.

No well-defined condensation. 13.5 mag.

1959
 Jan. 5-6 Diffuse round coma 8" in diameter. 13.5 mag.
 Jan. 10 Coma elongated in 65°. 13.5 mag.
 Jan. 28-31 Diffuse condensed coma 45" in diameter extending mostly in 30°. Total 13 mag.
 Feb. 2-7 Round coma 40" in diameter, centrally condensed. 13 mag.
 Feb. 28 Round coma 30" in diameter with a diffuse central nucleus 4" in diameter. 13 mag.
 Mar. 3-12 Image faint in hazy sky.
 Mar. 13 Round coma 25" in diameter centrally condensed. 13 mag.
 Apr. 4-6 Round coma 20" in diameter. 13.5 mag.
 May 2-6 15" diffuse coma. 14 mag.
 May 12 Faint on plate blackened by aurora.
 May 25 Faint at low altitude.
 June 2-3-4 Diffuse coma of 8" diameter. Faint at low altitude. 14 mag.

Comet 1959 b (Periodic Giacobini-Zinner)

1959
 July 2-3 Nearly stellar nucleus in a very faint round coma 10" in diameter. 18 mag.
 July 29 16 mag. Nearly round coma. Sky thick.
 Aug. 1 Small nearly stellar coma elongated toward 140° in which direction appears a tail 1' in length on this exposure. 15.5 mag.
 Aug. 2-5 15 mag.
 Sept. 5 12 mag.
 Sept. 22 11 mag. Coma strongly elongated in the direction of the tail in position angle 85°. 10 mag.
 Oct. 10 BD-17°5478-5- δ -2-BD-17°5453. Hence 8.0 total mag. Well-developed tail in 80°. 10 mag.
 Oct. 29 BD-17°5478-5- δ -2-BD-17°5453. Hence 8.0 total mag. Well-developed tail in 80°. 10 mag.
 Nov. 9 CoD-35°14086-5- δ -2-CoD-36°14147. Hence 7.7 total mag. Uncertain in moonlight. Sharply concentrated coma.
 Nov. 9 CoD-35°14086-5- δ -2-CoD-36°14147. Hence 7.7 total mag. Uncertain in moonlight. Sharply concentrated coma.

1960

Jan. 17 13 mag.
 Jan. 23 Centrally condensed round coma 13 mag.
 Feb. 15 Image very faint on plates fogged by moon. Mag. 14 uncertain.
 Mar. 1 15 mag.
 Mar. 19-20 Diffuse round coma 6" in diameter with a faint tail 1' long in 85°. Total mag. 15.

Comet 1959 c (Periodic Arend)

1960

Mar. 20-21 Not found anymore on 82" plates going down to 20 mag.

Comet 1959 e (Alcock)

1959

Sept. 1 Round coma 1'3 in diameter with a nearly stellar nucleus. Faint tail 4' in 95°. Total 10 mag.
 Sept. 5 12 mag.
 Sept. 22 Round coma 1'0 in diameter centrally condensed. 13 mag.
 Oct. 21 Faint round coma 8" in diameter. 18 mag.

Comet 1959 f (Alcock)

1959

Sept. 1 Even on this short exposure the coma appears already 1' in diameter making the measure uncertain. A 2-min. exposure guided for the motion shows a coma of 2' diameter and a tail over a degree in length consisting of a bundle of straight filaments spread over an angle of 20°. 15 mag.
 Sept. 2 Measure rather crude on the 2' coma in which the sharp nucleus can not be distinguished. A shorter exposure would have shown the nucleus but no comparison stars at this low altitude. The brightest filament in the tail shows a kink at 18' from the nucleus.

Sept. 3 Total magnitude 5.7 from an extra focal comparison with 60 Cor in a binocular.
 Sept. 4 Crude measure on large blob of coma. Binocular comparison with k Cor makes the total bright 4.9 mag.
 No trace of the comet was found after perihelion plates taken Oct. 18 and 23 with the 10" McDonald observatory in the position given. Candy's ephemeris (*I.A.U. Circ.* 1693) although stars down to 12 mag. were recorded.

Comet 1960 a (Burnham)

1960

Feb. 19-20 Diffuse round coma 10" in diameter. 17 mag.
 Mar. 1 Mag. 18.
 Mar. 19-21 Well-condensed diffuse coma with a faint tail in 100°. 18 mag.

Comet 1960 b (Wild)

1960

Apr. 22-23 Round-diffuse coma centrally condensed. Diameter 20". 16 mag.
 Apr. 25-27 17 mag.
 May 14 and 18 Strong exposures did not show the comet anywhere which must have been well below 18 mag.

Comet 1942 VII (Periodic Oterma)

1958

Apr. 8-17 Nearly stellar image of 18 mag. But on April 14 the image was less sharp than on April 8.

1959

Feb. 17 Almost stellar nucleus but there is a faint whisper a tail 1' long in 290°. 17 mag.
 Apr. 6 Fuzzy coma 10" in diameter. 17.5 mag.
 May 2 Same appearance. 17 mag.
 June 2-3 Image very faint in thick sky.

Comet 1925 II (Periodic Schwassmann-Wachmann 1)

1958

Aug. 12 Comet appears as a sharply defined nearly stellar nucleus of mag. 14 in the center of an extremely faint coma of 20" in diameter.
 Aug. 14 Exposed by C. Smith.

Aug. 15 Completely changed from Aug. 12. From a fuzzy nucleus emanates a broad fan between 20 and 140° position angle the brightest part being in the direction 40° and extending to 10'1 from the nucleus. Total 13.5 mag.

Aug. 16 Same appearance as yesterday but the fan extended to 14'7 from the center of the nucleus. Total 14 mag.

Sept. 12 Round fuzzy coma 25" in diameter centrally condensed. 18 mag.

Sept. 22 Nearly stellar nucleus with only the faintest indication of a diffuse coma. 15 mag.

Oct. 31 40" diameter coma with a centrally condensed fuzzy nucleus. Total 17 mag.

Nov. 1 Same appearance 16.5 mag.

Nov. 12 Very diffuse 18 mag.

Nov. 29 Well-condensed nucleus of 9" diameter in the center of round coma 1' in diameter. Total 14.5 mag.

Dec. 2 Same appearance but coma brightest in fourth quadrant. 15 mag.

Dec. 6 Coma brightest in first quadrant. Fuzzy nucleus 15.5 mag.

Dec. 9 Very diffuse. Hardly a nucleus. 16 mag.

1959

July 3 Small round coma 17.5 mag.

July 10 Small round coma 18 mag.

Sept. 1 Perfectly stellar image 12.5 mag.

Sept. 2 Perfectly stellar image 12 mag.

Sept. 3 Small coma 5" in diameter. 12 mag.

Sept. 8 Diffuse elliptic nebulosity 23-24". 14 mag.

Oct. 29 Centrally condensed in a round coma some 40" diameter. Total 14 mag.

Nov. 18-29 Extremely diffuse coma 17 mag.

Dec. 30 Diffuse coma 18.5 mag.

NOTES AND OBSERVATIONS

On the Photometric Catalogue of Stars in the Region of the Orion Nebula, Compiled by P. P. Parenago

1944 P. P. Parenago began a vast investigation of stars in the region of the Orion nebula. One of the interesting results was the establishment of an actual color-luminosity diagram for the studied stars (M. Walker discovered similar diagrams for several young star clusters). The first results on the basis of his new diagram were reported at the Second Conference on the Problems of Cosmogony on May 21, 1953, in Moscow (Parenago 1953). Brief conclusions published in the *Astronomical Circular* (Parenago 1953a) and the *U.S.S.R. Astronomical Journal* (Parenago 1953b). Full details of the investigation were given in an extensive monograph (Parenago 1954). It is interesting that this work remained little known abroad. Many authors refer only to the paper published in the *U.S.S.R. Astronomical Journal*. This fact led to a series of misunderstandings, connected with a wrong estimate of the value of the photometric measurements in this work.

Among the papers left by the late Prof. Parenago, a note was found, prepared for the press approximately at the beginning of 1959, in which a comparison was made between his system of stellar magnitudes and those of Sharpless (1952) and Johnson (1957). The note is as follows:

M. Walker (1956, 1957) thinks that my investigation of stars in the Orion nebula offers unsatisfactory observational data and that the colors and magnitudes of faint stars were determined from published reproductions of photographs. The fact is that 86 plates were used for determining photographic and photovisual magnitudes, proper motions and spectral types of stars. Most of these plates has been given (Parenago 1954). As there are hundreds of variable stars in the Orion nebula region, 35 reproductions were used (Parenago 1954) for supplementing the photometric data. Column 1 of my Catalogue (1954) gives the number of plates (first figure) and reproductions used (second figure). It can easily be seen that the reproductions are not the main source of information. The color-luminosity diagram first discovered in my work was correctly described by Walker (1956). I arrived at the conclusion that there was the following difference between my diagram for Orion stars and that of Walker (1956, 1957) for the young clusters NGC 2264 and NGC 2267: in the main sequence of my diagram there is a gap near A5 and then comes a "cloud" of subgiants, which in Walker's diagram reveals an increasingly separating branch containing A5-F stars as well as subgiants. I am convinced that this cloud is not a clear sequence, but is what P. N. Kholopov (1958) refers to later as the "T-band" for T-associations. It is difficult to tell as to who is right about the A5-F stars as it is not easy

to determine whether stars belong to the background or whether the majority of them are members of the given cluster. The same arguments can be applied to the diagram obtained by Johnson (1957) of a small number of faint stars, a third of which belong to the background, as confirmed by their proper motions.

"It is most surprising that A. Sandage (1958) considers my data unsatisfactory for stars fainter than 10 mag. My estimates of magnitudes and colors are of nearly the same precision for stars of 5 to 15 mag. and the main characteristics of the color-magnitude diagram have been revealed completely. It would be best, of course, to observe all (or many) stars of my Catalogue photoelectrically, but this requires much work.

"A comparison of my photographic (pg) and photovisual (pv) magnitudes of 102 stars (Parenago 1954) with photoelectric magnitudes derived by Sharpless (1952) and Johnson (1957) shows that the former are quite satisfactory from the point of view of the scale and precision. The reduction of my pv values to the V-system is constant and equals -0.1 mag. The scale of my pg values has the correction which follows for the B-system. I recommend its application for the rest of the stars in the Catalogue, until more precise determinations are made.

	pg	B-pg	pg	B-pg
> 6.1 mag.		0.0 mag.	14.0-14.3 mag.	-0.2 mag.
6.2-7.2		-0.1	14.4-14.6	-0.1
7.3-9.0		-0.2	14.7-14.9	0.0
9.1-11.1		-0.1	15.0-15.5	+0.1
11.2-12.0		-0.2	15.6-16.5	+0.2
12.1-13.9		-0.3	< 16.5	+0.3

"The mean square error of one Catalogue value is equal to ± 0.13 (pg) and ± 0.16 (pv), which coincides with the estimates given in the work itself (Parenago 1954)."

Thus, as we can see from the above quotation, the observational data used by Parenago are quite satisfactory and the main character of the color-luminosity diagram for stars of the Orion nebula was described by him with sufficient clarity.

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A. S. SHAROV
 Sternberg State Astronomical Institute, Moscow
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NEW BOOKS RECEIVED

Tools of the Astronomer by G. R. Miczaika and William M. Sinton, published by the Harvard University Press, Cambridge, Massachusetts, 1961. 294 pp. Price \$7.75.

This latest in the series of Harvard Books on Astronomy lives up to the high standard set by earlier volumes. Terse but remarkably comprehensive and readable accounts are given of photography, telescope optics and construction, the purely instrumental side of photometry and spectroscopy, solar instruments and radio telescopes. Well illustrated.

Rival Theories of Cosmology by H. Bondi, W. B. Bonnor, R. A. Lyttleton and G. J. Whitrow, published by Oxford University Press, 1960. 60 pp. Price 9s. 6d.

A pleasant compilation of four 1959 BBC talks on general relativistic (Bonnor), steady state (Bondi), and electric-charge-excess (Lyttleton), cosmological models, plus a discussion of the three points of view moderated by Whitrow. While there are no really new arguments, the respective views are well enough presented to make this little book worth browsing through by the average astronomer and astronomy student. (It might be noted that very recent work by Zorn and Hughes at Yale has shown that no difference in charge between electron and proton exists to even one-fifth the amount required for Lyttleton's theory.)